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Weeds

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Weeds

JOURNAL OF THE WEED SOCIETY OF AMERICA

VOLUME 8 OCTOBER 1960 NUMBER 4

Weed Control Research—Past, Present, and Future[1]

A. S. CRAFTS[2]

THE new scientific discipline, weed control, is the product of research. So long as man has grown crops for his own personal use, he has fought weeds, for nature favors community life for her plants. True there are examples of pure cultures of plants in nature; the white pine forests of the northwest, the buffalo grass prairies, wild rice in the northern lakes. But by and large, the areas now devoted to our major crops, wheat, corn, cotton and forage, were occupied by mixed plant populations and now they are in monoculture or in controlled plant populations and this nature abhors. Hence through the ages and even more today the farmer has been at war with weeds, the invaders of his crops.

But now the mode of warfare is changed. At last man has devised tools for combatting weeds, commensurate with the tools he uses for mining and manufacture and travel; modern mechanical and chemical tools; and these, I repeat, are the products of research.

Before I be accused of boasting I hasten to add that, as in all fields of research, many of the key discoveries in chemical weed control have come about by chance. When Bonnet, in the final years of the past century, observed that copper salts, applied to mixed plant populations, killed broad-leaved weeds without harming cereals, he was using Bordeaux spray to combat disease on his grape vines. Almost simultaneously and apparently by chance Schultz in Germany and Bolley in America found that strong salt and acid solutions would bring about this same result. The point I wish to make is that while these discoveries were apparently chance observations, they had to happen.

The stage was set; Liebig had elaborated his chemical theory of the nutrition of plants and proposed that plants obtain their nitrogen from the air as ammonia; Lawes had controverted this claim; chemists, and farmers, and amateur naturalists around the world

[1]Presidential Address, Weed Society of America, Denver, Colorado, February 23, 1960.

[2]Retiring President, WSA: Chairman, Department of Botany, University of California, Davis.

were playing with chemicals and plants. The fact that three, and possibly more, independent observations of the selective killing of weeds in cereal crops occurred almost simultaneously, was evidence that scientific agriculture had evolved to the place where differential wetting of mixed plant populations by toxic solutions had to be noted by someone. And so we may ask, was this in fact a chance discovery?

Following a brief flurry of interest, chemical control of weeds in cereal crops reverted to a slow and steady growth in Europe where grain growing was intense. By trial and error it was found that many salts and acids may serve as selective herbicides to kill broad-leaved weeds in cereal crops; examples are copper sulfate, copper nitrate, iron sulfate, sodium arsenite, and sulfuric acid. Through the years, because of economic factors, sulfuric acid emerged as the principal chemical used for this purpose, and a number of other crops including flax, peas and onions, were found to be amenable to selective weed control.

In America after some 12 years of experimentation Bolley published an Experiment Station Bulletin in North Dakota in which he said "When the farming public has accepted this method of attacking weeds as a regular farm operation, the gain..... will be much greater.....than that which has been afforded by any other single piece of investigation applied to field work in agriculture." Bolley had caught the vision, but like so many other scientists he was ahead of his time. While making slow but steady progress in Europe, selective control of weeds by chemical means languished in America. The concept was valid but the tools did not fit the job. And farmers in this expanding, pioneering agriculture were not interested.

At this point I should pay tribute to some of the pioneers of Europe. Morettini in Italy, Rabate in France, and Korsmo in Norway forged ahead applying new knowledge and new technics. In 1932 Korsmo published a monumental work in which he produced irrefutable evidence for yield increases in wheat, barley and oats following use of selective weed sprays. A survey of 211 experiments over an eight year period showed an average yield increase of 25 percent for sprayed plots over unsprayed. Sulfuric acid gave generally superior results although spraying with iron sulfate and nitric acid and dusting with kainite and calcium cyanamide was done.

The teen years of the twentieth century brought the next two important discoveries. In 1917 George P. Gray published in a California Agricultural Experiment Station Bulletin the observation that a dilute solution of sodium arsenite sprayed on bindweed within the fogbelt of coastal California, would kill the roots to a depth of several feet. This introduced the concept of translocated herbicides. I believe that Gray had this possibility in mind when he designed his experiments.

The second discovery was the chance observation that, when carbon bisulfide was applied as a soil fumigant in vineyards to control the root-borne disease *Phylloxera,* bindweed growing in the

treated areas was killed. Soil fumigation for controlling deep-rooted perennial weeds soon became a general practice. In this connection the careful experiments of Rogers and Hatfield published in 1929 in a Colorado Agricultural Experiment Station Bulletin should be mentioned. They placed soil fumigation for the purpose of killing weeds on a sound quantitative basis. Later work by Hagan and Hanneson at Davis emphasized the effects of soil structure and soil composition on the distribution of fumigants.

I do not know how sodium chlorate was first found to be a weed killer. During the early 1920's it was used to control vegetation along railroad rights-of-way in Germany and in 1926 Aslander reported experimental use of this herbicide in this country; he published more data in 1928. Although Aslander had discussed the fact that chlorate is effective applied through the soil, later workers used the chemical as a foliar spray apparently unaware of its effectiveness through the soil. By the middle 30's experimental work had proved that chlorates may kill leaves by contact action; that under proper conditions they may penetrate leaves, enter the xylem and move into roots, by reversal of the transpiration stream; that, when applied to the soil and leached in, they may be absorbed by roots resulting in death of the plants; and that when present in plants in sublethal concentration they may bring about a chlorotic, stunted growth of foliage from which the plant may recover; a common result of the presence of chlorates in plants is a reduction in their starch content.

Meanwhile field testing had proved the great toxicity of sodium arsenite to plant foliage and this material became the standard weed spray throughout this and many other countries. And tests in California showed that an acidified solution of sodium arsenite, applied to deep-rooted perennial weeds under proper conditions would penetrate the foliage, enter the xylem and move deep into the roots. This acid-arsenical spray, a modification of George Gray's original material, became quite widely used in the Western United States and in Australia. Careful plant physiological research was utilized in developing this method to its maximum effectiveness.

Pastac in France discovered that sodium dinitrocresylate would selectively kill broadleaved weeds in cereals in 1933; four years later this chemical was introduced into the United States and tested widely. And in 1939 a curious Oregon farmer, wishing to fertilize his grain crop and kill weeds at the same time, found that addition of ammonium sulfate to the dinitrocresylate spray greatly enhanced its toxicity. Thus activation of dinitro compounds was discovered by chance. The chemical mechanism of this activation was worked out and published in 1945; it was effective not only on dinitro compounds but on sodium pentachlorophenate as well.

I do not need to describe the introduction of 2,4–D in 1944 as you are all familiar with that story. It is interesting to note, however, that the first publication on this compound as a weed killer in America described its use as a translocated spray on bindweed and in Britain it was first used as a selective soil sterilant. Only after its

public introduction was its use as a selective spray in cereal crops discovered; use by the low-volume method followed soon after tests by MacDonald of the Peevey Co. carried out in California. MacDonald proved that application in a volume of 6 gallons of spray liquid per acre was as effective as in 160 gallons. Thus, for the first time, a chemical weed control method that was cheap, effective, and practical for large scale application became available. Within a year acreage treated with herbicides increased from a few thousand to several million; chemical weed control became a going business.

Meanwhile careful research was developing a body of data related to the toxicity of herbicides in soils, and the effects of soil factors on their availability to plants. Again the stage was set so that when Anderson and Ahlgren and Anderson and Wolf announced the successful use of 2,4–D as a pre-emergence application in corn, this method was immediately recognized as a new breakthrough in the chemicalization of agriculture. Tillage for weed control, abandoned since the 30's by certain citrus growers in California was now dispensable in the growing of corn and other row crops. A true revolution was at hand.

I need not dwell on the announcement of IPC by the group working at Camp Dietrick, of chloro IPC by Freed in Oregon, of endothal by the Sharples Company, Alanap and MH by Naugatuck, of the substituted ureas by duPont, the chloroacetamides by Monsanto, of the thiol and dithiocarbamates, the symmetrical triazines, of amino triazole and dalapon and chlorobenzoic acids and the great numbers of analogues of 2,4–D by chemical companies in this country and abroad. You have all lived through these exciting years; the methods of synthesis, screening, and testing are familiar; millions of man-hours are being consumed and millions of dollars spent in this search for new and better chemical agents. But, what about research?

It will be years before the plant physiologists and biochemists can possibly work out the mechanisms of absorption, translocation and lethal action of the chemicals we now have on hand. The new methods of autoradiography, counting, and chromatography are greatly speeding our work and still we lag away behind. We know that herbicides may penetrate the cuticle and that under other conditions they may enter the leaves via an aqueous route. We know that stomatal penetration is effective but not necessary, and that it cannot be depended on for all absorption. We know that some herbicides enter the symplast, move into the phloem and translocate with foods to sinks in roots and shoot tips, flowers and fruits; others enter only by roots and move to tops in the transpiration stream. We know that some herbicides act as mitotic poisons on meristematic cells, others uncouple the respiration mechanism, some are transformed to toxic forms by beta oxidation, some inhibit the Hill reaction, some interfere with pantothenate metabolism.

But the true selective mechanism of 2,4–D is still obscure; we don't know that the blocking of the photolysis of water is the whole mechanism of action of the ureas and triazines; the mechanism of

toxic action of the chlorobenzoic acids is not understood, for these compounds are apparently not used up in the killing process.

Much of this research will have to be accomplished in Universities and government supported laboratories for only in these does the proper environment for basic research exist. Few chemical companies can afford the research necessary to a complete understanding of the action of the compounds they produce; their laboratories are under too much pressure for immediate answers to allow for the quiet, contemplative type of study required to solve these problems.

And so our new discipline of weed control must span the hurried torrent of modern chemical discovery, providing information in the diverse fields of synthetic chemistry, phytopharmacy, plant physiology, plant biochemistry, agronomy, horticulture and economics. Is it any wonder that Warren Shaw has a furrowed brow, that Dr. Willard needs help to get our journal out on schedule, and that Fred Slife needs a sabbatical leave?

Well, so much for modern research in weed control.

Some of you may feel that I have spent too much time dwelling on the "glories of the past." You say "the past is dead, we live in the present, what about the future?" To you I reply that I have not been merely reporting. What I am saying is that the present is born out of the past and that the future depends on both. Our discipline was not born over-night. It is not just a collection of chance discoveries. Weed control did not start in 1944 with the discovery of 2,4–D. With all due respect to Kraus and Templeman and Sexton and Blackman, we must remember that Darwin observed the turning of the oat coleoptile toward the light in 1880; Went proved the existence of the plant hormone in 1926; Zimmerman and Hitchcock synthesized and tested 2,4–dichlorophenoxyacetic acid and many of its analogues in 1942. While the discovery of the herbicidal action of 2,4–D came about in America as the result of the stimulating atmosphere of war, in Britain the concept of the absolute hormonal control of plant growth had arrived some years before. The herbicidal properties of 2,4–D could not have remained in obscurity for a single year in the upsurge of plant physiological research that followed the war. This was a concept that had to be born. Considering the mass of basic research on cell physiology, plant biochemistry and hormone mechanism that was accumulating, the discovery of the herbicidal properties was inevitable. Like the discovery of atomic fission and antibiotics the sum total of knowledge of plant response to growth regulating chemicals had grown to a state where a major advance in the area of plant control was overdue.

And so with many of the other concepts that are coming from our present research. Biochemists have worked out the details of the respiration cycles; discover a chemical that blocks any step in these complex processes and you have a potential herbicide. Hundreds of plant enzymes are now known; find a chemical that interferes with the smooth function of any of these and you have a potential herbicide. Antiauxins, super auxins, antimetabolites, protein coagulants,

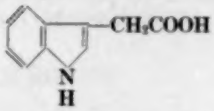
simulated viruses, these and a hundred other types of compounds offer promise; these are the modern reagents to use; they constitute the tools of the present day weed researcher.

What of the future? I'm afraid that many of you will be disappointed in my answer, for I am not a crystal ball gazer. I have no fears for the future of our new discipline. I already see piled up problems that will keep most of us busy for years. I will close by quoting the answer that I habitually give to question No. 6 on our O. E. S. form 8, the annual report on our Experiment Station Project. To the question "Work planned for next year", I always reply, "Studies on the uptake, distribution, and mode of action of herbicides will be continued."

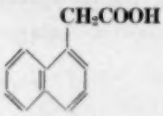
The Role of Chemical Research in Developing Selective Weed Control Practices[1]

H. Gysin[2]

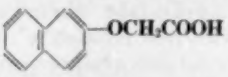
Shortly after 1934 when Kögl and co-workers found that indole–3–acetic acid



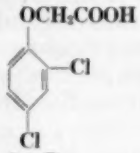
is a substance which has cell elongation activity in plants, many attempts were made to find other chemicals showing an indole–acetic–acid-like activity. It is 25 years now since Zimmermann and Wilcoxon found that naphthyl–1–acetic acid



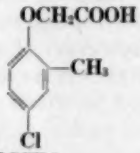
and some other aryl–acetic acids are active plant regulating compounds also. With these experiments it could be shown that the indole–nucleus is not essential for a plant growth regulator. The findings of Irvine showed that 2–naphthoxy–acetic acid



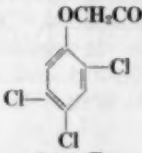
is equally active as a phytohormone. This indicates that the acetic acid has not necessarily to be linked to the naphthalene ring directly. The naphthoxy–acetic acid was further modified chemically and became the starting point for the most widely used phytohormones: 2,4–D, MCPA and 2,4,5–T.



2,4–D



MCPA



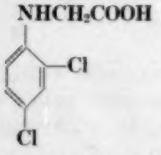
2,4,5–T

The history of the discovery and investigation of 2,4–D and MCPA never became completely clear to the outsider as the initial work was done during the war and was covered by secrecy regulations. From 1942 on various laboratories in the world made a concentrated effort

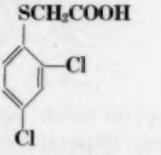
[1]Paper given at the General Session, Weed Society of America, Denver, Colorado, February 23, 1960.

[2]Geigy Chemical Corporation, Basle, Switzerland.

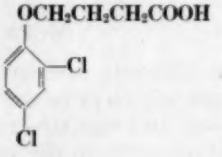
to find within this general group of chemicals more active or more selective compounds. This effort led to the discovery of quite a number of 2,4– or 2,4,5–substituted phenol derivatives with side-chains being acetic–, propionic–, or butyric acid. This proved to be a most fruitful line of investigation as a dozen or more products resulted from it and are on the market today. In addition to the alteration of the structure of the side-chain of 2,4–D, other ways were followed with the goal to change the activity of 2,4–D and the like. If the oxygen atom of phenoxy–acetic acids is replaced by an amino group or by a sulfur atom the respective 2,4–dichloro–phenyl–glycine



and the 2,4–dichloro–phenyl–thio–acetic acid



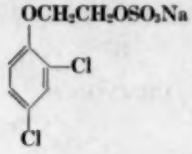
are still active growth regulators. As Wain gave a comprehensive study on the chemical structure in relation to the growth regulating properties of the 2,4–D–type chemicals in the second volume of "Advances in Pest Control Research", I may be permitted to make a few further remarks on this chapter only: Quite a number of factors are known today which seem to be responsible for the activity or inactivity of substituted phenol–, naphthol–, phenyl–, indole–fatty and the substituted benzoic acids. It seems, however, premature to use for the synthesis of new compounds in this field existing theories only and to synthesize only chemicals which fit the theoretical requirements. According to the still widely accepted two-point theory for example a 2,6–dichloro–phenoxy–acetic derivative should be inactive. It was found, however, that 2,6–dichloro–phenoxy–acetamide has a considerable activity. Another good example how biological effects may be changed by altering the structure is 2,4–DB:



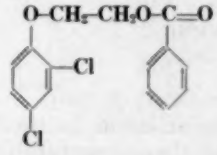
2,4–DB

It could be shown that this compound is much more selective than 2,4–D and various investigators especially Wain and his co-workers

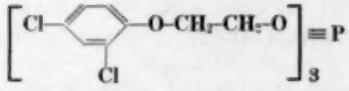
could find the explanation of this increased selectivity. Some plants are able to transform 2,4–DB by β–oxidation into the active 2,4–D while others do not possess this oxidation system and, therefore, remain unaffected. It was very fortunate that many weeds are able to produce this conversion more effectively than the crops so that this phenomenon is applicable practically. Another attempt to mask the active principle and to leave it to secondary factors to transform the compound into an active chemical is sesone:



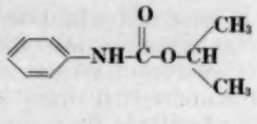
It is believed that this compound can be oxidised, being a derivative of 2,4–dichloro–phenoxy–ethanol, to 2,4–D. Sesone applied to the foliage of a plant is not active per se but is oxidised in the soil to 2,4–D. 2,4–Dichloro–phenoxy–ethyl–benzoate (2,4–DEB)



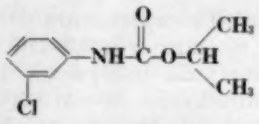
and tris–(2,4–dichlorophenoxy–ethyl) phosphite (2,4–DEP)



are based on the same principle. They are of low activity when applied on the foliage but are converted in the soil to the active herbicide. Their conversion time is dependent on the soil moisture and temperature as is their residual effect. In addition to the phenoxy–fatty acid derivatives the carbamate herbicides are another field where the relationship between chemical structure and herbicidal activity was studied. As early as 1929 phenyl urethane was known as a germination inhibitor. It was, however, only due to Templeman and Sexton that 15 years ago a comprehensive study was made on a number of aryl–carbamic esters. While on the one hand the replacement of the ethyl alcohol in phenylurethane by isopropyl alcohol led to a considerable increase of activity, the introduction of a chlorine atom into the phenyl-ring, especially in 3–position doubled or tripled the activity. The introduction of a chlorine atom into IPC-yielding chloro–IPC (CIPC)—increases the resistance of this latter compound to a microbial breakdown in the soil and prolongs its residual effectiveness:

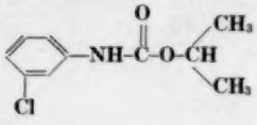


IPC

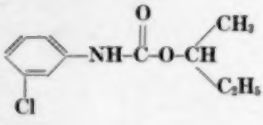


CIPC (much more active than IPC)

Shaw published in 1953 a study on the activity of some 45 carbamates and could show that secondary butanol used instead of isopropanol in CIPC led to a slightly more active carbamate:

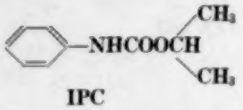


CIPC

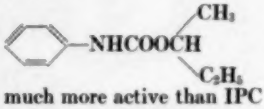


slightly more active than CIPC

If the same change is made in IPC a much more active compound is obtained in the secondary butyl analogue:

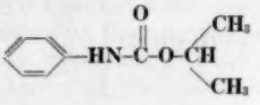


IPC



much more active than IPC

In addition to the chlorine atom in the 3–position of the phenyl ring a methyl group in the same position does not alter fundamentally the activity of CIPC:

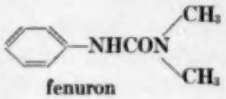


highly active

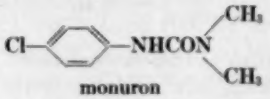
3–CH_3	highly active
3–NO_2	moderately active
3–OH	trace of activity

But substituents such as the nitro– and especially the hydroxy–group lead to a considerable or total loss of the herbicidal activity. The introduction of different substituents into various positions of the phenyl ring alters the selectivity considerably. Some compounds such as CIPC as well as the analogous secondary butyl ester control broadleaf weeds *and* grasses while IPC for example does not control crabgrass and mustard but is effective on ryegrass. The widespread idea that the carbamates substituted in the phenyl ring with various atoms or groups behave like IPC, which controls predominantly grasses and leaves broadleaf weeds untouched, is only partly true. Some selectivities of carbamates are primarily of positional nature only. According to Shaw this is especially true for grass crops such as corn and wheat, while cotton is physiologically more resistant to the carbamates.

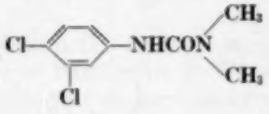
The next interesting group where a study of the structure and activity could be made is the urea group. Asymmetric substituted ureas can be made in a practically unlimited number. From the outside it is difficult to judge how many ureas were synthesized and tested by the DuPont investigators. From the various patents issued the number must be quite considerable. Among this great variety of compounds a chemically closely related group has found so far the most interest. These chemicals are fenuron, monuron, diuron and neburon. They all have in common a phenyl ring which is either unsubstituted or substituted in para respectively in 3,4–position by a chlorine atom. The aliphatic part is either dimethylamine or in the case of neburon methylbutylamine.



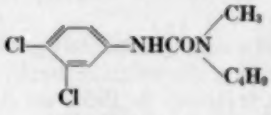
fenuron



monuron

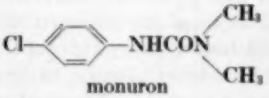


diuron

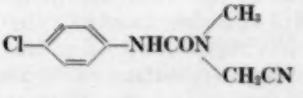


neburon

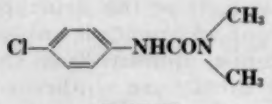
Due to the different solubilities of these chemicals in water and organic solvents, their behaviour in soil is different. While fenuron and monuron are leached to deeper root zones, diuron and neburon stay near the very surface. The difference in absorption on the soil may be another important factor in the reaction versus plants grown in soil. With the solubility the absorption is likely to be as deciding a factor as the absolute phytotoxicity in this group of compounds. As very little is published on the structure/activity relationship in the urea group, my description is far from being complete and is based on a small number of representatives only. The ureas with the best herbicidal activity known to me are the asymmetric aryl–alkyl–ureas. Ring-substituents which are favorable are halogen especially chlorine atoms, but alkoxy–phenyl–alkyl ureas are active also. The aliphatic substituents are preferably low alkyl groups. According to investigations done independently by BASF and Geigy, N. Y., the dimethyl–amino group in monuron and the like can be replaced by a methyl–cyano–methyl–amino group whereby the herbicidal properties remain, but the compounds are less stable and did not find a practical use:



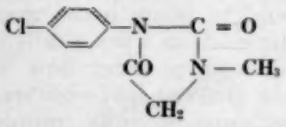
monuron



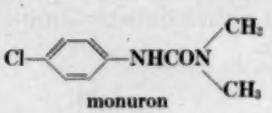
By hydrolysing the cyano-group the respective hydantoins are obtained which are still active.



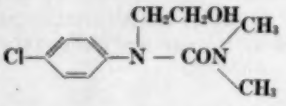
monuron



In order to decrease the residual effect of monuron, BASF researchers claim that hydroxy–alkyl–substituted monuron-like ureas show promise as selective weedkillers:



monuron

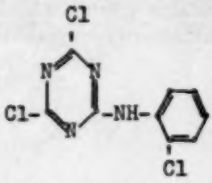


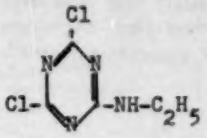
By substitution of the oxygen atom by a sulfur atom in the monuron-type ureas some herbicidal activity remains, but generally the thio–ureas show an inferior activity in comparison with the analogue ureas.

Let me turn now to the only group I can speak of our own investigations, namely, the triazine herbicides. When we started to synthesize and test triazines in 1952, we decided to screen all our new compounds in Switzerland as well as in the United States to give the chemists the best possible guidance. The methods used consisted in germination and phytohormone tests which differed somewhat in the two laboratories. They were followed by pre- and post-emergence applications of the herbicide candidates. We used this double-check procedure for more than two years when it became evident that the agreement between the test-laboratories had reached such a perfection that we could give up the screening work in New York. Since 1955 only the promising compounds are being sent to this country. Here they are tested under various conditions on a variety of crops by our own people as well as by Federal and States Research workers. Only due to this help from USDA-, University- and Experiment Station-scientists it was possible for us to evaluate the herbicidal properties of a large number of chemicals in a relatively short time. I should like to express at this place my very sincere thanks to all biological workers in this country who took an active interest in our compounds. I hope that they will keep their enthusiasm for new compounds in the future also. In this way the farmer can expect to get more and more selective compounds and his goal to replace the hand-weeding completely may be reached some day.

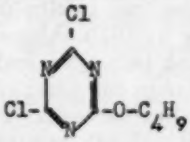
Let us draw our attention in the first place to the triazines which have still 2 chlorine atoms in the ring. It could be shown that the triazines having in addition to the two chlorine atoms groups bound over an oxygen or sulfur atom and over amino groups respectively are of particular interest. If in cyanuric chloride one of the three chlorine atoms is replaced by one of the above mentioned groups we have to differentiate between products which have predominantly

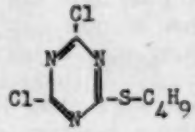
fungicidal or herbicidal properties. Wolff et al. found that 2–arylamino–, especially 2–chloroanilino–4,6–dichloro–*s*–triazines have considerable fungicidal activity. If instead of an *anilino* an *aliphatic amino* group is in 2–position of a 4,6–dichloro–triazine, the compounds are good contact herbicides:





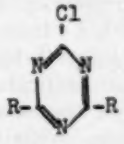
So the substitution of a phenyl ring by an alkyl group results in a fundamental change of the biological properties. If the aliphatic amino-group in a 2–alkyl–amino–4,6–dichloro-triazine is replaced by alkoxy– and alkylthio-groups respectively the compounds remain herbicidally active.





These dichloro–alkylamino–, alkoxy– and –alkylthio–triazines are relatively unstable chemicals. With an increased chain length the stability towards hydrolysis is somewhat increased, but it is doubtful that these compounds on which Koopman and co-workers published will ever find a practical use.

Due to the nearly unlimited number of 2–chloro–4,6–disubstituted triazines which can be synthesized, I should like to discuss this group in various subdivisions



R =		activity	
	O–aryl	0	a.)
	O–alkyl	+	b.)
	N–aryl	0	c.)
	N–aralkyl	+	d.)
	N–alkyl	++++	e.)

a) 2–Chloro–4,6–bis–aryloxy–*s*–triazines and their sulfur-analogues respectively have—as described by Wolff—some fungicidal activity but are of no practical value as selective herbicides.

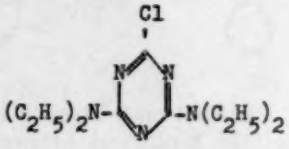
b) 2–Chloro–4,6–alkoxy– and –alkylthio–*s*–triazines respectively are significantly more active as herbicides than the aryl–analogues but their activity is a mediocre contact toxicity only.

c) 2–Chloro–4,6–bis–arylamino– or 2–chloro–4,6–bis–N–alkyl–N–aryl–amino–*s*–triazines which are told by Wolff to have some fungicidal activity also are practically inactive up to 50 pounds/acre as herbicides.

d) 2–Chloro–4,6–bis–aralkylamino–*s*–triazines, however, show definite phytotoxic activity.

e) As soon as the aromatic amines are replaced by aliphatic amino groups thus forming 2–chloro–4,6–bis–alkylated amino–*s*–triazines the picture is fundamentally changed as within this group of chemicals there exists a large number of very effective herbicides.

Historically the first active chemical of this group which we synthesized was the 2–chloro–4,6–bis–diethylamino–*s*–triazine known under the generic name *chlorazine:*



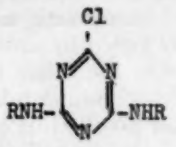
This compound is very stable in neutral and alkaline solutions while in strong mineral acid solutions even at room temperature hydrolysis takes place. The water solubility of chlorazine is in the order of 10 ppm only. On the herbicidal activity of this compound we published a short note in Experientia in 1955. Already in the first screening tests it became evident that this chemical did not possess any phytohormonal activity and that in the germination test a little effect was evident 10 days after application only. The young growing plants, however, died between 10 and 20 days after treatment when the compound was thoroughly mixed with the soil at the beginning of the experiment. In a pre-emergence test 10 pounds chlorazine per acre killed mustard and oats after 20 days. In pre-emergence field screening tests on a variety of crops it became evident that this compound kills or seriously injures in dosages of 10 lb/A most weeds and crops with the exception of corn where no phytotoxic symptoms could be noticed at all. These observations were the starting point for the synthesis of a long series of triazine-compounds. A considerable number of these chemicals were tested in addition to the laboratory- and greenhouse-tests in the field. I cannot name all the persons who were involved in this project but I wish here to thank all my co-workers, the chemists Rumpf and especially Knüsli, the biologists Gast and Grob, who did most of the screening and field screening work respectively, and Roth, who made a thesis on the metabolism of triazines in plants. I wish to extend my thanks to the analytical chemists for the development of micro-and macro-analytical methods, to the biochemists who helped to elucidate the mode of action of the triazine herbicides and to the toxicologists and pharmacologists for their valuable data on the behaviour of triazines on various laboratory animals.

For the following discussion of the 2–chloro–4,6–bis–alkylated–amino–*s*–triazines I wish to choose arbitrarily two subgroups:

a) the symmetrically substituted 2–chloro–4,6–bis–alkylated–amino–*s*–triazines

b) the asymmetrically substituted 2–chloro–4,6–bis–alkylated–amino–s–triazines

a) *Symmetrical 2–chloro–4,6–bis–amino–s–triazines*
The simplest derivative of the series, the 2–chloro–4,6–bis–amino–*s*–triazine, is of no activity at 10 lb/A. The lowest symmetrical 2–chloro–4,6–bis–alkylamino–*s*–triazine, the 2–chloro–4,6–bis–methylamino–*s*–triazine is slightly active only.



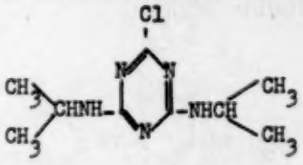
R =		activity
	—H	0
	—CH_3	+
	—C_2H_5	++++
	—CH(CH_3)(CH_3)	++++
	—CH_2–CH=CH_2	++
	—$CH_2CH_2CH_3$	+

simazine
propazine

But already the next homologue of this series is the best 2–chloro–triazine having two identical substituents in 4- and 6-position known so far; it is the 2–chloro–4,6–bis–ethyl–amino–*s*–triazine: *simazine*. By increasing the chain length of the amino-groups to three carbon atoms three derivatives are possible:

2–Chloro–4,6–bis–isopropylamino–*s*–triazine
2–Chloro–4,6–bis–allyl–amino–*s*–triazine
2–Chloro–4,6–bis–*n*–propylamino–*s*–triazine

of which the first, *propazine*, is the most interesting one:



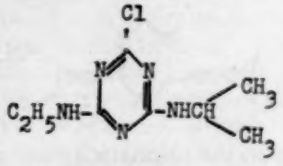
One carbon atom more in the aliphatic amino groups leads to weaker herbicides already and in comparison with simazine and propazine they are of no practical interest. It is unbelievable what differences in the biological behaviour occur with these "minor changes" in chemical structure. The physical properties of all the mentioned 2–chloro–4,6–alkylamino–*s*–triazines are more or less the same; they are extremely little soluble in water: simazine 5 ppm, propazine 9 ppm etc., they are high melting, tasteless and colourless materials, of mammalian toxicities in the range of 5 g/kg. But some cause phytotoxic reactions on a wide variety of plants and are not effective on a relatively small number of crops or weeds in dosages of 1–5 pounds per acre. Some are active in higher dosages only. Those derivatives which are not active at 10 pounds per acre are arbitrarily claimed inactive.

It is outside of the scope of this lecture to try to discuss all the selective herbicidal properties of the active triazines. I should like, however, to draw your attention on relatively small groups of compounds, closely related chemically but showing characteristic differences biologically. The components I wish to compare with each other of the first pair are:

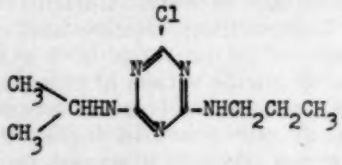
Simazine : Propazine.

Both compounds have a low solubility in common, they are slow acting, but they have—applied in dosages of 10 and more pounds per acre—a residual effect of a year or even more. Both compounds are practically active through the roots only and crops tolerant to these chemicals are corn, asparagus, sugar cane, grapes, all kinds of trees etc. There exist, however, remarkable differences between simazine and propazine. Sorghum, carrots, celery, fennel are rather tolerant to propazine while these crops are mostly killed by simazine in dosages necessary for selective weed control. On the other hand there exist distinct differences between the two compounds on weeds also: wild carrot (*Daucus carota* L.) is not controlled by propazine while simazine in the same dosage gives a complete kill of this weed. Bindweed (*Convolvulus arvensis* L.) is one of the weeds which are rather resistant to simazine and even dosages of 10 lb/A only stunt the growth of this weed while 10 lb/A of propazine in grapes are able to control *Convolvulus* completely under the same conditions. This complete control may be reached, however, only after many months.

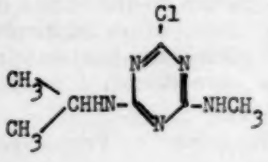
b) *Asymmetrical 2-Chloro-4,6-bis-amino-s-triazines*
In the asymmetrically substituted 2-chloro-4,6-alkylated-*s*-triazines we found a number of interesting compounds. By far the best chemical of this group is the 2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine: *atrazine:*



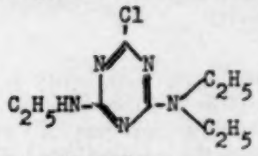
This herbicide is acting more rapidly than simazine and is active against a variety of weeds and crops to which simazine is inactive. Within this group there exist also differences in the selectivity as described before between the symmetrical compounds simazine and propazine. According to Shaw, G 30,451



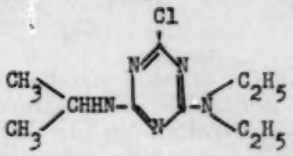
kills walnuts, peanuts and chestnuts to 100% at dosages of 4 lb/A while these crops tolerate G 30,026



at the same dosages, the weed control of the grasses and the broadleaf weeds being practically identical. Lima beans and soybeans are completely killed by G 30,026 at 2 lb/A while G 30,451 causes slight injuries at the same dosage to these crops only. Another interesting group consists of asymmetric chloro–triazines being substituted by one primary and one secondary amino-groups. The two most valuable representatives of this type are trietazine and ipazine



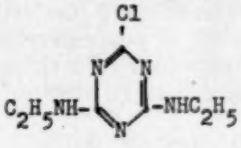
Trietazine



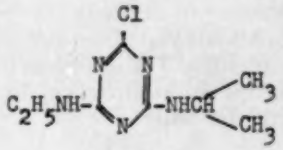
Ipazine

In the screening tests these two compounds behave on a large number of test plants very similarly. Under field conditions trietazine shows selectivity to tobacco, soybeans and peas while ipazine looks promising in cotton. Here also the replacement of one ethylamino-group by an isopropylamino-group causes significant differences in the selective herbicidal properties.

Perhaps the most striking differences are noticeable in comparing a representative of the symmetrical and the asymmetrical chloro–triazines. A typical pair of this kind is



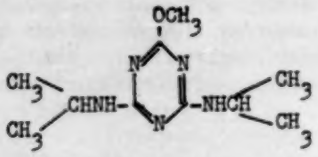
Simazine



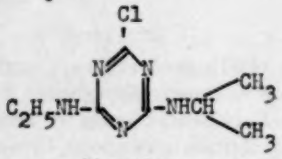
Atrazine

Simazine does not penetrate through the leaves and applied as a post-emergence herbicide the activity is through the roots. This is completely different for atrazine which is active even if any root uptake is prevented by covering the soil. Atrazine is about 15 times as soluble in water as simazine and the difference in the solubilities in organic solvents is even more pronounced. It can be expected that deep rooted crops and weeds are more susceptible to atrazine as it is likely to be leached deeper into the soil. It was not foreseeable, however, that this difference in solubility was sufficient to allow the penetration through the leaves for one chemical and to prevent it for the other. In addition to this phenomenon the two chemicals behave in some cases differently where the differences in the solubilities cannot be the explanation for their different biological behaviour. *Panicum* varieties, especially *Panicum sanguinalis*, are controlled fairly well by simazine while atrazine is much inferior against this weed. The same difference exists for *Sorghum halepense* which is not controlled even at fairly high dosages with atrazine. We assume, therefore, that these differences are due to physiological reasons and are not based on the different solubilities of atrazine and simazine respectively.

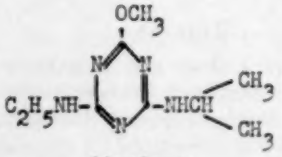
If in simazine or related chloro–triazines the chlorine atom is replaced by an alkoxy–, especially by a methoxy group, other interesting herbicides are obtained, e.g. *prometone:*



From the physical standpoint the increased water solubility is the first noticeable phenomenon. While the most soluble among the active 2–chloro–4,6–bis–alkylated–amino–*s*–triazines has a water solubility of 250 ppm, the methoxy analogues have water solubilities between 750 and 3500 ppm. This increased solubility enables the 2–methoxy–triazines to enter into deeper root zones. There is, however, a marked difference in the biological behaviour of the methoxy-derivatives as they do not show by far the same degree of selectivity to corn and similar plants. We do not have sufficient data yet to draw conclusions if in this case the rate of uptake of the methoxy–triazines by corn is considerably higher than for the chloro–triazines so that an eventual detoxification does not take place in a rate sufficient to prevent an accumulation of a phytotoxic level in the plant *or* if in this case the corn plant does not possess the system necessary to detoxify the methoxy–triazines. Most of the 2–methoxy–4,6–bis–alkylated–amino–*s*–triazines can be used as post-emergence herbicides. The difference in the biological behaviour of a chloro–triazine in comparison to a methoxy–analogue may be illustrated with the pair:



Atrazine

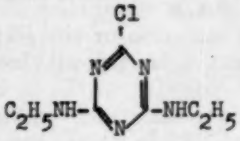


Atratone

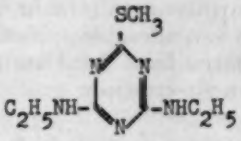
Amounts up to 10 lb/A atrazine applied pre- or post-emergence are harmless to corn while the same or even considerably smaller amounts of atratone kill or seriously damage this crop. Crops like grapes are much less sensitive to atrazine than to atratone while for beans the contrary is true. Several millet varieties are rather tolerant to atrazine, but are controlled by the same dosages of atratone.

In dosages of 10 to 40 pounds the methoxy triazines proved to be very valuable non-selective herbicides, especially for deep rooted perennial grasses. They can be used either alone or in combinations with simazine or atrazine. Prometone used with a phytotoxic oil at the right growing period is a good brush killer. The volatility of some methoxy–triazines is much higher than for the chloro–triazines: when heated over a period of 31 days at 70° C, 21% of prometone evaporates while simazine and the like disappear to less than 2%.

If the chlorine atom in simazine is replaced by an alkyl–mercapto– especially by a methylmercapto–group another interesting series can be obtained:



Simazine

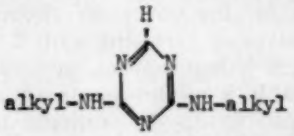


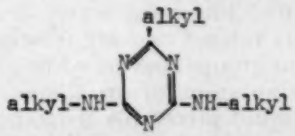
Simetryne

In the group of 2–methylmercapto–4,6–bis–alkylated–amino–triazines we found in the recent past a number of triazines which look very promising. The active representatives of this series have a markedly reduced residual activity in comparison to the methoxy–triazines and especially to the chloro–triazines, thus enabling a use where long residual effects have to be excluded. Generally this group has a somewhat different selectivity in comparison to the other active triazines. Especially some small grains such as barley and wheat, which normally are quite sensitive to triazines, show a somewhat increased resistance to some representatives of the mercapto–triazine group. Corn is about as sensitive to the mercapto–triazine–series as to the methoxy–triazine compounds. Crops such as peas, beans, rape, vetch etc. are fairly resistant to the methyl–mercapto–4,6–bis–alkylated–amino–*s*–triazines. We hope that these compounds will be available in the forthcoming season to interested research workers.

For the comparison of the chloro–bis–alkylated–amino–*s*–triazines and the methyl–mercapto analogues I chose the pair simazine/*Simetryne* which latter is the generic name for 2–methylmercapto–4,6–bis–ethylamino–*s*–triazine. The solubility of Simetryne in water is 450 ppm or about 100 times higher than that of simazine. The appearance of the first phytotoxic symptoms occurs faster than in the case of simazine or of most methoxy–triazines. The residual activity of 1–2 pounds of Simetryne is less than 2 months and even the most sensitive crops can be planted after ploughing the soil previously treated with Simetryne or another mercapto–triazine after 3 months. Simetryne has a very high activity applied as post-emergence herbicide and little selectivity. The short lifetime of Simetryne may be of considerable interest for fall or early winter treatments.

If the chlorine atom in simazine and the like is replaced by a hydrogen atom 4,6–bis–alkylated–amino–*s*–triazines are obtained:

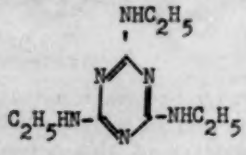


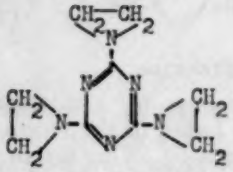


Their activity is considerably lower. But an enhanced phytotoxicity appears as soon as instead of the hydrogen atom a lower alkyl-group is the substituent in 2-position of the 4,6–bis–alkylated–amino–*s*–triazines. Compounds of this structure have to be synthesized by a

Grignard-reaction or from suitable guanamine derivatives and their production costs are, therefore, considerably higher. In preliminary field tests no specific selectivity could be determined so that this group seems to remain of rather academic interest only.

When the chlorine atom in 2-position of simazine or the like is replaced by a third amino-group thus forming 2,4,6–tris–alkylated–amino–*s*–triazines





these chemicals have interesting phytotoxic properties also. In comparison to the 2–chloro–4,6–bis–alkylated–amino–*s*–triazines, however, they are generally of lower activity. Due to their slight basic properties they may be bound to the soil so that they may be inactivated to a higher extent than the chloro-analogues. Practical tests in 1959 with a number of representatives of this class were not promising enough that further investigations are indicated. A compound belonging to the tris–amino–substituted–triazines is the 2,4,6–tris–ethylen–imino–*s*–triazine. This chemical found considerable interest in cancer research. Due to its structure analogy it was tested in our herbicidal screening tests but did not prove to be active. So apparently due to their cross-linking properties the ethylimino groups are responsible for the cytostatic activity as the herbicidally active triazines of the simazine type do not inhibit the mitosis of the animal cell.

In addition to the various groups I have discussed so far, we synthesized a great many more triazines and a number of analogues of other heterocyclic ring-systems. Generally speaking none of the derivatives surpassed the activity of the best triazines. Some are tested at the time being to such an extent that no definite conclusions can be drawn.

As far as I am able to summarize what we know today about the chemical structure in relationship to the herbicidal properties of the triazine group, the following looks to me as to be a fair statement of the present status of our work:

In the series of substituted symmetrical triazines we found a large number of derivatives which show various degrees of herbicidal activity. The most active herbicides of this series are chemically closely related and are mostly derivatives of *s*-triazine with 2 alkylamino groups and in addition either a halogen atom, preferably a chlorine atom, or an alkoxy—preferable a methoxy—or an alkyl–mercapto, preferably a methylmercapto group. In addition to the two compounds simazine and atrazine, which found so far a practical use as industrial weed killers and as selective herbicides in various crops, propazine, prometone and atratone are in the process to be marketed in this country also, while they are commercialized in

various other countries already. A number of further triazines are tested in the USA and abroad. Slight alterations in the chemical structure lead to considerable differences in the biological behaviour of the various triazine–derivatives. In general the substituents leading to the most active triazines are low alkyl radicals bound over amino groups, oxygen or sulfur atoms and halogen atoms directly linked to the triazine ring. Additional work is necessary to fully evaluate the triazine group. My paper today is a summary of the present status of the investigations in this field only. I hope some day to be able to present you a more complete survey.

If you ask me now what is the role of the chemical research in the development of selective weed control practices I wish to sum up my answer in the following way:

Chemical research is the basis for the development of selective herbicides. The efforts of the synthetic organic chemists have to be guided by their botanical colleagues. The chemical research is, therefore, the first link of a long chain. This first link consists of a little inspiration and a lot of transpiration. It requires patience, confidence and an enormous amount of time and money. A research problem has to give satisfaction to all concerned. The team, consisting of organic, analytical and bio-chemists, biologists, field research workers etc., confronted with the task to develop a selective herbicide must be properly guided so that it can function as a research unit. These conditions have to be coupled with a great deal of optimism to continue a task to the final success whatever difficulties may have to be met. All this taken for granted asks a good dose of luck at the right time, then a new useful product will be the result of the combined efforts sooner or later.

Research and Organizational Needs in the Field of Weed Control[1]

M. W. Parker[2]

It is indeed a real pleasure for me to have the opportunity to participate in this third meeting of the Weed Society of America. The years I spent in the Weed Investigations Section were among the most rewarding of my professional life.

The last time I spoke at a formal meeting of weed specialists, some four years ago, I made a plea for more basic research on the metabolic action and fate of herbicides in plants and soils, and for more botanical knowledge of the weeds themselves. It has been encouraging to note in your journal "Weeds" that many more papers in these areas are appearing. Continued advancement in weed control will depend on such knowledge. The "spray and watch" approach accomplished a great deal during the past decade. Advancement in the future, however, will call for a more fundamental approach.

I would like to discuss some of the research needs as they appear to me at this time. But before I go into the research itself, I want to stress the need for additional scientists who will devote their full time to weed control problems. We need more scientists trained in basic sciences such as chemistry, physics, and mathematics. We need agronomists, horticulturists, botanists, and physiologists. And we need still others trained as extension specialists. Weed-control problems today are so complex and varied that a team approach is fast becoming a necessity for maximum accomplishment.

I do not rule out the outstanding contributions that will inevitably be made by the brilliant researchers who prefer to work alone. Actually, we have a place and a need for both individual and team research, but the group approach is proving extremely effective in speeding progress on many difficult research problems.

Research on weed control should give increasingly more emphasis to the development of new principles. A striking example of such a development is typified by the action of 4–(2,4–DB) and simazine. The plant itself determines the selectivity of the herbicide. Those species of plants with an enzyme system capable of beta-oxidation of 4–(2,4–DB) to 2,4–D are killed, and those that do not have such a system will tolerate the chemical. Simazine, on the other hand, is metabolized by some species of plants, notably corn, to inactive materials and is therefore highly selective in its herbicidal activity.

More research on the interaction of plant and chemical will unquestionably result in the development of additional compounds with specific selectivity. Progress will come as we gain more complete

[1]Paper given at the General Session, Weed Society of America, Denver, Colorado, February 23, 1960.

[2]Director, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Washington, D. C.

understanding of plant metabolism and knowledge as to the part that each chemical constituent of a herbicide contributes to its activity. The ideal herbicide is one that can be sprayed on an emerged crop without damage to the young plants or soil, and still control weed growth. We must continue the search for herbicides that more nearly meet this desirable prerequisite. The more thorough our fundamental knowledge of chemicals, plants and soils, and their interaction, the greater the chances of success in discovering and developing improved selective herbicides.

We also need more fundamental information on the interaction of temperature, moisture, light, and soil from the standpoint of their effects on the selectivity and fate of herbicides. Controlled environmental growth rooms are very useful for this type of experimentation. However, the lack of such facilities does not preclude the study of some of the interactions cited. Great discoveries have been made with the simplest equipment,—improvised by the scientists to seek new facts.

We know that changes in the environmental complex can greatly modify plant growth, development, and composition. Unquestionably, plant response to applied chemicals is also affected by such changes. The microorganisms in the root zone of the soil can also play an important role in the activity of herbicides. For example, soil organisms are known to convert 2,4–dichlorophenoxyethyl sulfate (sesone) into the active compound 2,4–dichlorophenoxyethanol, thus permitting the safe use of sesone on crops that are injured by foliage application of 2,4–D.

In studying the interrelation of environment and herbicidal activity, we should not overlook the possible importance of atmospheric environment. Recent research with tobacco has shown that high concentrations of ozone in the atmosphere result in leaf damage known as tobacco fleck. The question naturally comes to mind as to the effect air pollutants might have on herbicidal activity.

Recent developments have pointed up the necessity for a more concentrated research effort to determine the fate of herbicides and other pesticides in plants and soils. We must gain a better understanding of the penetration, absorption, translocation, accumulation, and degradation of all the chemicals applied to plants and soils. We know very little, for example, about the degradation products of most herbicides in plants and soils. And we know still less about them in warm-blooded animals. Perhaps the recent attention given to residues in cranberries, and the resulting effect on the entire field of chemical weed control, can be turned into an advantage by providing the stimulus for more aggressive research on the fate of herbicides and other chemicals in plants, soils, and animals. The information obtained would permit more efficient use of chemicals, and would be extremely helpful in the evaluation and interpretation of residue data required for chemicals to be applied on food and feed crops.

More consideration should also be given to the role of plant genetics in the development of herbicides and other pesticide chemicals. Tests conducted at the Welsh Plant Breeding Station in Wales

and by USDA at Beltsville, Maryland, have shown that DDT is phytotoxic to certain barley varieties and not to others. Crosses between susceptible and resistant varieties show that this resistance is controlled by a single recessive gene. In studies of the commercial varieties of barley grown in the United States and Canada, only 4 percent were found resistant. Two varieties showed a mixed reaction. In tests of a composite mixture of the world collection of 5,000 varieties, 10 percent were found resistant to DDT.

This genetic control for reaction to DDT leads to a consideration of the possible existence of similar genetic control systems in other plants and for other chemicals. Certainly a much better job of pest control could be done if the plants to be protected were resistant to the chemical used. This is a fertile area for research, and one that has been little explored. It will require both the chemist and the biologist—the chemist to develop selective chemicals and the biologist to discover genes in world plant sources that will resist these chemicals. The dual goal will be protection of the economic crop from both chemical and pest.

So far, I've been stressing better methods for controlling weeds with chemicals. The need is equally great for more research on biological control methods. We've only just begun to learn the potentials of insects, plant pathogens, and other organisms as tools for weed control. The most dramatic example has been the successful introduction of the Klamath weed beetle to control Klamath weed on western rangelands. The replacement of weeds with more valuable plant species is another practice that should be given due consideration in our development of a total weed control program.

As I mentioned at the beginning, there has been some increase in reports of botanical research on weeds. But we need much more information on the life history of individual weeds, with emphasis on special weaknesses that might occur during development. These weaknesses might well be used for advantage in a control program. If we could discover a practical method of breaking dormancy of weed seed and buds on perennial plants, our problems in weed control would be greatly reduced.

There should also be increased expansion of our research to give greater depth of concentration and a more vigorous attack on particular weeds and the problems associated with them in different crops and situations. The time has passed when a weed researcher can "work across the board" and expect to come up with the specific answers to specific weed problems. Here is where a team approach, based on keen and unstifled individual initiative, is especially needed. Within the past few months, we have assembled a team of five scientists, including agronomists, physiologists, and a biochemist to develop information for the control and progressive eradication of witchweed in the Carolinas. Equally strong emphasis should be given to research on Canada thistle, Johnsongrass, nutsedge, and many other important weeds.

At the same time, we should not lose sight of the overall weed problems on a farm or in an area. As additional herbicides, with specific activities on different spectrums of weed populations are

introduced, there is an increasing need to determine and understand the ecological shifts in the weed populations. Strains may evolve that are resistant to standard herbicides, and new methods of control will need to be developed. A satisfactory weed control program for the total farm or area will necessitate the development of methods for controlling weeds in the various crops grown in rotation, and thereby the various herbicides employed will be involved. Rotational use of herbicides in different crop rotations will bring pressure on a wider spectrum of weed species than would occur otherwise, but we must have full knowledge as to the effect such practice will have on soils and soil microorganisms.

I recognize that all of the needs for additional research outlined here cannot be met with the personnel and funds now available to us. I am convinced, however, as opportunities occur for expanding research or for making shifts in present programs, that more attention should be given to these major problems of weed control.

As many of you know, the original Division of Weed Investigations in the USDA was formed in 1949, with a staff of 12 scientists. This organization has remained intact and the staff has increased fivefold. There are now 62 professional staff members in weed investigations. We are proud of the achievements that these scientists have made. They, along with their associates in the State Agricultural Experiment Stations and industry, have succeeded in developing selective herbicides that have made it possible to completely mechanize the production of several major crops.

It is my opinion that some of this success can be attributed to the fact that our weed specialists have been retained in a single organizational unit rather than being assigned to specific crop groups. I believe the type of organization we have maintained is especially important when a new science is in the formative years of its development. The main problem is to be sure that all areas of research that need attention are adequately covered.

I am convinced that real advantages would be gained by having units of weed control specialists in all of the State Agricultural Experiment Stations. To do an adequate job, these units should include both research workers and extension specialists. The staff members may be housed in any appropriate department, depending on the local situation. The important consideration is that in their joint efforts they function as a unit.

The founding of the Weed Society of America was a significant step forward in meeting one of the organizational needs in the weed control field. This Society can fulfill national needs that cannot be met by the regional weed conferences. This was recognized when the four regional conferences banded together to charter the national organization. The regional Weed Conferences serve an extremely important function by providing for an exchange of information and ideas that aid greatly in the rapid adoption of improved weed control practices. We in the Department do have one rather important problem in connection with the current practice of holding three regional conferences and the national meeting all in the same year. This means that some of our members, who have only

limited opportunity for travel, must choose between attendance at a regional conference or at the national meeting. I believe this matter of multiplicity of annual meetings deserves the most serious consideration by all who are interested in weed control research. The constitution of the Weed Society of America provides ample representation from all regions, and I believe it should be the dominant professional society for all scientists interested in weed control research.

The Society already has several outstanding accomplishments to its credit. One of these deserves special commendation—that is the progress made in promoting and adopting common names for herbicides and weeds. Faulty and uncoordinated terminology can seriously handicap communication between scientists and industrial developers and consumers. The complete chemical name for a compound along with its accepted common name should be given when the chemical is first cited in a manuscript. Thereafter, in that particular paper, only the common name need be used. This policy is now followed in the Crops Research Division and we are striving to have it adopted throughout the Department.

Another outstanding accomplishment of this Society is its official journal "Weeds". A comparison of current issues with earlier ones will show the vast improvements that have been made in the presentation of research results. The journal is helping to emphasize that among the most important objectives expected of research scientists are the recognition of problems, establishment of a priority for their solution, conceiving, planning, and conducting basic and applied research, and the analysis, interpretation, and publication of the results. Too often the job of analysis, interpretation, and publication of research is neglected. More attention needs to be given to publishing weed-control information in journals that will provide for the greatest use of the information by scientists and the general public.

The role industry is playing in the rapid development of chemical weed control is indispensable. The cooperation between industrial and public agency scientists in the synthesis, introduction, and development of new herbicides has been of the highest order. Public Law 518 and the Delaney Amendment pose problems that will require even closer teamwork between industry and public agency scientists in assuring the efficiency and safety of new chemicals.

Extension personnel and others responsible for educational programs for farmers also have an increasingly important job of training users of herbicides and other pesticide chemicals to use these materials according to directions of manufacturers and in line with approved procedures.

Chemicals will continue to be used in modern agriculture. It is our responsibility to continue to develop the essential information necessary to insure their effective and safe use in food and feed production throughout the country. We have the most wholesome supply of food on earth today, and we all share the desire to keep it thus in the future.

Weed Control—Its Status and Organisation in Great Britain[1]

E. K. Woodford[2]

It is a great privilege and a pleasure to have this opportunity of discussing with you the status and organisation of research and development work on weed control in Great Britain. We have followed with keen interest the formation and growth of your "Weed Society of America" and have greatly enjoyed papers from your secretary, Dr. Warren Shaw, and your past president, Dr. Bob Beatty, at our own British Weed Control Conferences. Your immediate President is an especial friend of ours and it was while he was working with us in Oxford two years ago that he received intimation of his election to this post.

Contacts between our two countries on this subject are becoming much closer. In the industrial sphere, the increasing interest in exports, the growth of associate Companies, and the complicated arrangements of licenses for the sale of each others products on both sides of the Atlantic, often makes it difficult, for those of us who are not versed in the ways of big business, to distinguish between North American and European interests. In academic and official circles too, there seems to be a healthy growth in the interchange of research personnel. Until recently the British economy and the status of our subject made it difficult for many of our research staff to visit your country. Conditions are, however, changing and we hope that in the years ahead it will be possible for more of us to see, at first hand, the tremendous strides you have made in the practical application of herbicides.

The realisation that we have much to learn from each other was brought home to me very strikingly when I made an extensive tour of your country in 1954. It is a joy to be back again, to renew old acquaintances and to make new ones at this Conference. I bring you greetings and good wishes from the British Weed Control Council and from our friends in Continental Europe.

Dr. Warren Shaw suggested originally that I talk to you about Weed Control in Europe, but as Europe is rather a large place and as I have not even set foot in many of the countries of which it is composed, I have decided to confine my attention primarily to Great Britain. I want to start, however, by assuring you that as far as weed control research is concerned, we are making real progress in European co-operation and that important developments have taken place during the last two years.

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[1]Paper given at the General Session, Weed Society of America, Denver, Colorado, Feb. 23, 1960.

[2]Agricultural Research Council Weed Research Organisation, Oxford, England.

EUROPEAN CO-OPERATION

The history of this co-operation dates back to May, 1958, and the 10th International Symposium on Phytopharmacy at Gent. The Belgians took the opportunity afforded by this gathering to call a meeting of those interested in weed control in order to consider "greater international co-operation in weed research." Many European countries were represented and the meeting agreed to set up an "Informal Research Group" under the presidency of Professor B. Rademacher. The first technical Conference of this group took place on the 3rd and 4th March, 1959, at Stuttgart-Hohenheim in Germany. It was patronized by the European Productivity Agency of E.E.C. and attended by 50 research workers from 14 European countries. This Conference, in turn, appointed an Interim Council to consider the formation of a more permanent organisation and asked it to make recommendations for consideration at the next meeting of the "Group" which will be held at Oxford, England, on the 5th and 6th of April this year.

The "Interim Council," of which I have the privilege of being Chairman, has been busy and although the report has not yet been made public, I am sure it is in order for me to let you know our main recommendations.

We have decided that with the multilingual association of people that exists in Europe there would be few benefits to be gained, apart from the levying of membership fees, from forming a weed society of the type that you have in the U.S.A. Instead we are advocating the setting up of a "European Weed Research Council." The primary object of this Council would be to facilitate the exchange of scientific knowledge between research workers interested in weeds and their control. In order to accomplish this object we suggest that the Council undertake, (a) to sponsor the holding of symposia on special aspects of weed research, and, (b) to arrange for the publication of a new journal of Weed Research. This journal we suggest should be trilingual (English, French and German), concerned primarily with the science of weeds and their control, but also catering for the more technical agronomic aspects of the subject. In addition, we suggest that arrangements should be made for the Journal to publish the proceedings of the symposia held periodically in different European countries.

There seems to be every likelihood that these plans will succeed, and that the first issue of the Journal will appear in March, 1961.

With this brief introduction about developments in Europe as a whole I must now turn to the position in Great Britain and first, perhaps, I should remind you of the nature of our agriculture.

BRITISH AGRICULTURE

Of the 50 million people who live in Great Britain, approximately 23 million are gainfully employed and of these a little over 1 million work on the land. These million agricultural workers produce approximately 45% of the calorific requirements of our people, and

in order to help them do this they receive annual grants from the State amounting to at least 700 million dollars, and representing about 60% of their net earnings. This State aid is distributed by a variety of means, such as price support schemes, production grants and direct subsidies. Farmers, for instance, receive substantial contributions to the cost of apply fertilizers, liming, ditching, draining and improving farm buildings. In addition, grants are available for ploughing land that has been down to grass for more than four years and for the improvement of upland and hill areas.

The only subsidy given specifically for weed control is the "Bracken Eradication Grant" which entitles farmers to receive half the cost of cutting bracken *(Pteridium aquilinum)* for three years. As yet there are no direct grants for applying herbicides, but the cost of such treatments can be included in farm improvement schemes and if a suitable chemical can be found for the control of bracken, it would undoubtedly be eligible for a subsidy. Such a possibility has stimulated industry to take much interest in this weed and extensive trials to test the efficiency of dalapon, amino triazole, and 4–chlorophenoxyacetic acid (4–CPA) have been laid down. They show that 4–CPA formulated as an invert emulsion is the most promising.

It might be assumed from the magnitude of the grants and subsidies given to British farmers that they are perhaps not making full use of all the modern methods that are available to them for increasing the efficiency of production. This is perhaps true of the smaller holdings, and unfortunately more than half the farms in England and Wales are less than 50 acres. The 'small income farmer' is in fact one of the most difficult problems facing progress in British agriculture. It is, however, a sociological problem which agricultural science can only partly resolve. Gradually these farms are being consolidated into larger units in order to permit the use of mechanised equipment and the up to date methods of farm management so essential to the business of modern farming and already we have the situation where 20% of the farmers are producing 80% of the total produce. These efficient business men could well do without the government subsidies so essential to the small farmer.

The situation, therefore, is very different from that which exists in the U.S.A. where there is so much fertile land and where agricultural scientists and farmers have apparently worked so efficiently together that production has been increased to the stage where your government has to pay subsidies to avoid surpluses. Another important difference in our agricultural economies is that, as yet, we have no real shortage of labour. In consequence, herbicides are used primarily to increase the efficiency of production and rarely because labour is not available.

British farmers have come to concentrate on a limited number of products that they can sell in the home market against foreign competition and which are suited to the climate and soils of the island. Since much of Wales, Scotland and Northern England is hilly and with a rainfall between 30–70 inches, it is not surprising

that most of the agricultural land is grass and that most of the agricultural revenue comes from livestock and their produce.

The acreage of the main agricultural crops grown in Great Britain is shown in Table 1.

Table 1. Acreage main agricultural crops in Great Britain.

	Millions of acres		
	1957	1958	1959 (provisional)
Temporary grassland	5.7	5.7	6.2
Permanent grassland	12.3	12.2	12.0
Total	18.0	17.9	18.2
Cereals			
Wheat	2.1	2.2	1.9
Barley	2.6	2.7	3.0
Oats	2.1	2.0	1.8
Rye	0.03	0.02	0.01
Mixed grain	0.3	0.3	0.23
Total	7.13	7.2	6.9
Potatoes	0.7	0.7	0.7
Sugar beets	0.4	0.4	0.4
Turnips, swedes, mangolds	0.6	0.6	0.6
Kale and other fodder crops	0.5	0.5	0.5
Total	2.2	2.2	2.2
Bare fallow	0.3	0.3	0.4

HERBICIDE USAGE

Agriculture.

It would be interesting to put against the acreage figures of Table 1 the percentages treated with herbicides. Unfortunately this is not possible, for although we know that the quantities of herbicides used on British farms, and particularly on cereals, has increased very rapidly during the last 12 years, there are no official statistics to show the magnitude of this change. Unlike the U.S.A. and some Continental European countries, the British Government keeps no record of the quantities of herbicides bought by growers. They do, however, record the number and types of machines owned by farmers and the increase in ground crop sprayers from 9,000 in 1952 to 33,000 in 1956 gives an indication of the rapid expansion in the use of crop protection chemicals that took place during this period.

Last year our "Unit" at Oxford, in conjunction with Rothamsted Experimental Station, carried out a small pilot survey of farms in North Oxfordshire in order to assess the acreages of the different crops treated with herbicides. A summary of the results obtained is shown in Table 2. The pattern of use must vary greatly from one part of Britain to another, but these figures, which show that 8% of the grassland and 47–61% of the cereal acreage was sprayed, are probably somewhere near the mean for the country as a whole.

Horticulture.

The acreage of the main horticultural crops grown in Great Britain is shown in Table 3. For these crops there are no data at all

Table 2. Estimated percentage of acreage of individual crops treated with any herbicide (North Oxfordshire).

	Per cent treated
Grassland (total)	8
Cereals	
Wheat	47
Barley	60
Oats	61
Potatoes (haulm destruction)	40
Turnips, mangolds, etc.	Nil
Kale	14

Table 3. Acreage main horticultural crops in Great Britain.

Vegetables	Nearest thousand acres			
	1956–7	June 1958		June 1959
	Cropped area	Cropped area	Returned area	(Provisional) Returned area
Brussel sprouts	49	45	48	50
Cabbage, savoys, etc.	80	70	50	45
Cauliflower and broccoli	34	40	31	32
Carrots	32	34	34	32
Peas, green for market	36	35	35	29
Peas, green for canning and freezing	48	59	59	67
Peas harvested dry	105	72	72	56
Total vegetables, flowers and nursery stock (excluding potatoes)	466	488[a]	447	429[b]
Fruit	**Returned area**	**June, 1958**		**(Provisional) June, 1959**
Strawberries	17	18		18
Raspberries	3	10		11
Black currants	10	13		13
Apples, cider	39	41		not available
Apples, dessert and cooking	128	119		not available
Pears, perry	3	3		not available
Pears, dessert and cooking	18	18		not available
Plums	38	33		not available

[a]Flowers and nursery stock figure for "returned area", 30 thousand acres.
[b]Includes "crops grown under glass or in frames" (5 thousand acres for 1957 and 1958).

concerning the acreage treated with herbicides. It cannot, however, be very large except for carrots and peas, as there are no herbicides recommended for the first three groups in the vegetable list (brussel sprouts, cabbages, savoys, cauliflower, broccoli, etc.) and a limited number for use in fruit crops. Market gardeners and fruit growers are nevertheless showing a tremendous interest in herbicides and are not waiting for official recommendations before trying any new proprietary that is offered.

A stage has been reached in many horticultural crops, which is comparable to that which existed in cereal crops ten years ago. Progress, however, is unlikely to be as rapid as it was in cereals because of the limited interest of both commercial and official organisations in research and development work. In addition, the market is not particularly attractive to Industry as the acreage of

the individual crops is small and the weed control requirements often very specific.

HERBICIDES FOR AGRICULTURAL CROPS

In Table 4 are listed the herbicides recommended for application to agricultural crops and those that have proved promising.

Table 4. Herbicides for agricultural crops.

	Recommended	Promising
Grassland	MCPA, 2,4–D, MCPB	
Cereals	MCPA, 2,4–D, MCPB, 2,4–DB, CMPP, DNC MCPA/TbA, MCPA/MCPB, DNBP, H_2SO_4	"barbane" "Avadex"
Potatoes	MCPA	dalapon, DNBP
Sugar beet	$NaNO_3$, PCP, TCA	endothal, IPC
Peas	DNBP, MCPB, TCA	CIPC, diuron
Beans	DNBP, simazine	CIPC, diuron
Turnips, swedes, etc.	Nil	EPTC
Kale	H_2SO_4, SMA	EPTC, amiben
Alfalfa	DNBP, 2,4–DB, CIPC, dalapon	

Although the pattern of herbicide usage for the crops listed is similar the world over, there is plenty of scope for variations on any particular theme due to differences in weed species, soils and climates. In your vast country, you must be very familiar with such variations and the differences that they call for in chemicals and techniques. Even in England the weed flora changes from one county to the next and our soils are probably as variable as in any country of the world. Such differences within and between countries, and the patterns of herbicide usage that result, are extremely important and deserve much more study than they have so far received.

Our weed problems are not the same as any that exist in North America, but approximate most closely to those that prevail in parts of Oregon. For this reason we are particularly interested in the applied research that is carried out in that part of your country.

Time does not permit me to consider each of the crops listed in the Table 4. I would, however, like to enlarge a little on the situation as it exists in cereals for this is our most important arable crop and the one in which the application of herbicides has been the most rewarding.

Cereals.

The nine different chemicals officially recommended for application as post-emergence treatments to cereals are given in Table 5. With these we can kill most weeds except wild oats (*Avena fatua*) and black grass (*Alopecurus myosuroides*). Several of these are obtainable either as alkaline metal salts, amines, or esters and all are available in many proprietary formulations. Of these herbicides MCPA is by far the most widely used, but each type has its own particular advantages and disadvantages and all are still required as components in the chemical armoury of the cereal grower. The choice of which chemical to use, depends essentially on three considerations—safety,

toxicity to weeds and cost. The crop situations for which it is safe to apply the different herbicides are shown in Table 5. The relative susceptibility of the important weeds of cereals, at least 25 in number, has been worked out and is available in Ministry leaflets and in our "Weed Control Handbook". The comparative prices of the different herbicides, when applied by the farmer, are given in the right hand column of Table 5. With such information it should

Table 5. Herbicides (X) for selective weed control in cereal crops.

Herbicide	Autumn sown	Spring wheat				Spring barley				Spring oats				Relative price when applied by farmer
	Spring treatment	Not under		Under		Not under		Under		Not under		Under		
		E[a]	L[b]	E[a]	L[b]	E[a]	L[b]	E[a]	L[b]	E[a]	L[b]	E[a]	L[b]	
MCPA	X		X				X			X	X			1.0
2,4–D	X		X				X				X			1.0
MCPB	X	X	X	X	X	X	X	X	X	X	X	X	X	2.5
2,4–DB	X		X		X	X	X	X	X	X	X	X	X	3.0
2–(MCPP)	X	[d]	X			X	X			X	X			2.0
MCPA/TBA	X		X				X				X			2.0
H_2SO_4	X		X				X				X			2.0
DNC	X		X				X				X			3.0
DNBP	X		X		X		X		X		X		X	3.0
MCPA/MCPB	X		X				X				X			2.0

[a]Early. Cereals with 2–4 leaves.
[b]Late. Cereals with 5 leaves to fully tillered.
[c]Undersown.
[d]Variety Koga II only.

theoretically be possible for farmers to make the correct choice. In practice, however, few farmers have the time or the inclination to delve so deeply into the matter. They use MCPA whenever possible, because it is safe and as cheap as 2,4–D, and when a choice has to be made they leave it to their merchant or the manufacturers technical representative. We have, in fact, reached the situation where the subject is really too complicated to expect the farmer to understand and our problem now is how to ensure that he obtains the correct advice.

HERBICIDES FOR HORTICULTURAL CROPS

The herbicides recommended for use on vegetable and fruit crops are shown in the second column of Table 6. As I have already stated, there are no herbicides available for our most important vegetables, brussel sprouts, cabbages, savoys, cauliflowers, nor do there seem to be any really promising new materials in sight (Column 3). Carrots, peas, beans, onions, sweet corn and the hardy asparagus are fairly well taken care of, but we do badly need a satisfactory herbicide for lettuce. In bush and tree fruits dalapon and simazine are proving promising and becoming more widely used. The whole subject of the application of herbicides to horticultural crops is however, still in its infancy.

Table 6. Herbicides for horticultural crops.

	Recommended	Promising
Vegetables		
Brussels sprout	Nil	
Cabbage, savoys, etc.	SMA	
Cauliflower, etc.	Nil	
Carrots	Mineral oils	propazine, amiben
Peas	DNbP, MCPB, CIPC	
Asparagus	MCPA, monuron, simazine, dalapon	
Beans	DNBP, CIPC, PCP	diuron, amiben
Lettuce	CIPC	
Onions	Acid H_2SO_4, SMA	CIPC, diuron, atrazine
Sweet corn	simazine, 2,4–D	
Fruit		
Strawberries	DNBP, CIPC, 2,4–DES	simazine
Bush and cane fruits	dalapon, simazine 2,4–DES	
Apple	MCPA, dalapon, simazine, monuron	
Pear	dalapon	

ORGANISATION OF RESEARCH AND EXTENSION WORK

With this brief review of the position of herbicides in agriculture and horticulture let me now turn to a consideration of the status of weed research in Great Britain and the organisation of our research and advisory services. In Britain as in many other countries, weeds received comparatively little attention until selective herbicides became available. After the discovery of MCPA and 2,4–D there was a marked change in outlook and many more people are now concerning themselves with weeds. "Pure" botanists working in the Universities no longer regard weeds as species to be avoided and there has been a noticeable increase in studies of their botany and ecology. Weed control is, however, still very much of a technology studied only in Agricultural Research Institutes and we are a long way from establishing the science of the study of phytotoxic chemicals.

Figure 1 shows the way in which our research and advisory services are organised. There are two important points to note. First, that the organisation in England and Wales is quite different from that in Scotland, and second, that the agricultural research service is not administered by the Ministry of Agriculture, but comes under the Privy Council and the Minister of Science.

Agricultural Research Service.

Agricultural research is the responsibility of the Agricultural Research Council, a body which was set up in 1931 and which now supervises the activities of between 30 and 40 Institutes and Units. Eleven Institutes and three Units are concerned with plant science; weeds and weed control are studied, in varying degree, at most of these. The National Vegetable Research Station has a section on weed ecology under H. A. Roberts and the Scottish Horticultural Station is forming a section to study herbicides. The other crop stations rely on the part time work of agronomists.

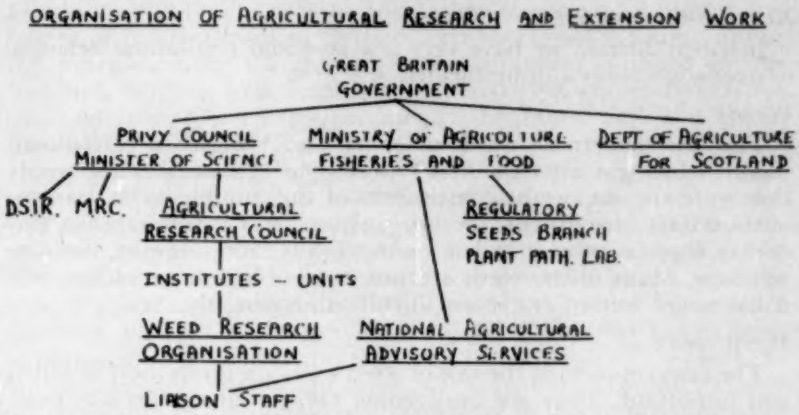

Figure 1. Organization of agricultural research and extension in Great Britain.

The national centre for weed research is at Oxford where Professor Blackman has for the last 14 years been directing a team of workers interested in both the fundamental and applied aspects of the subject. The work undertaken by this "Unit of Experimental Agronomy" has grown steadily over the years and has now reached the stage where it can no longer be contained by the University. This April, therefore, the Agricultural Research Council are setting up a completely separate and independent organisation in the vicinity of Oxford to be known as "The Weed Research Organisation." This organisation, which I have been asked to direct, will take over and enlarge the applied research that was formerly carried out by the Unit within the University. In addition, it will become the centre for all official work on herbicides. It will prepare the monthly journal "Weed Abstracts" and take a leading part in editing the new Journal of Weed Research.

Extension services.

Advisory or extension duties as well as some development work are undertaken in England and Wales by The National Agricultural Advisory Service. This organisation, which came into being as recently as 1946, is a part of the Civil Service. It operates from eight regional centres at each of which are stationed husbandry and science specialists. The former include crop husbandry, grassland husbandry and horticulture, the latter, bacteriologists, chemists, entomologists and plant pathologists. Weed control is not considered as a separate technology requiring its own staff in the regions. Instead specialists are attached to the Weed Research Organisation which will become the centre for both extension and research work.

In Scotland the organisation is quite different. The Advisory services are centred at the Agricultural Colleges which form part of the Universities in much the same way as in your country, but there are no weed specialists.

Regulatory activities.

In Great Britain we have very few laws and regulations relating to weeds, weed seeds, or herbicides.

Weeds.

The law concerning weeds dates back to 1921 when agriculture was in a bad way after the first World War. It prescribes the weeds that were the important constituents of the 'tumble-down' pasture of those days; two thistles, *Cirsium vulgare* and *Cirsium arvense,* two docks, *Rumex crispus* and *R. obtusifolius,* and ragwort, *Senecio jacobaea.* Many other weeds are just as troublesome nowadays, but it has never seemed really worthwhile amending the Act.

Weed seeds.

The laws concerning the sale of weed seeds are much more detailed and important. They are undergoing revision at the present time. Among other things, they lay down the percentages or numbers of injurious weed seeds permitted in crop seeds offered for sale. The new legislation will probably lay down stricter limits for:

Wild oat *(Avena fatua, A. ludoviciana)*
Dodder *(Cuscuta* spp.)
Docks and sorrels *(Rumex* spp.)
Blackgrass *(Alopecurus myosuroides)*
Couchgrass *(Agropyron repens)*

Herbicide sales.

The laws relating to the sale of herbicides must be unbelievably simple in comparison with your own. There are in fact no legal restrictions on the type of herbicide offered for sale unless the chemical is a scheduled poison and appears on the poisons list. The only herbicides at present on this list are DNC, DNBP and alkali arsenites. All other chemicals can therefore be sold without restriction. In practice, however, herbicide manufacturers work very closely with the Government organisations concerned with these problems and have recently agreed to a voluntary scheme which requires new crop protection chemicals to be submitted for official clearance before they are sold to the public. This "Voluntary Notification Scheme" came into operation in 1957 and appears to be working satisfactorily.

Safety of operator.

We do not have laws concerning the protection of all who apply toxic chemicals. The regulations detail the type of clothing that the operator must wear and the procedure he must follow when applying "scheduled" herbicides. At the present time these are DNC, DNBP, alkali arsenites, endothal and sulphuric acid.

Safety of public.

When it comes to the protection of the public, either as growers of plants or as consumers of treated crops, we again rely on non-regulatory measures. We have no laws or regulations restricting the way in which herbicides are applied. Instead, reliance is placed on ensuring that the user is fully informed of the dangers, if any, of the

herbicides and hoping that he will follow them. An Advisory Committee of the Government Departments concerned examines spraying practices and with the help of information supplied by the Research Stations and manufacturers make recommendations for their safe use. These are then widely distributed and it is hoped followed in practice.

In comparison with your own regulations relating to tolerance levels, our lack of controls must seem almost too naive to be true. Our Government has, of course, given serious thought to the institution of tolerances either legal or voluntary. As you are well aware, there are many difficulties and drawbacks to such a system, not the least of which is the responsibility of ensuring that the tolerances are observed. Perhaps the best system will be a combination of both recommendations for use and tolerance limits. This is how Dr. J. T. Martin recently summed up the position in Great Britain "Under the conditions of production and marketing in this country, reliance solely on tolerance observance for consumer protection would be unsatisfactory; it would not only be costly, but to a large extent, impracticable. On the other hand, a tolerance is of value in indicating the level of spray residue to be avoided and in providing a basis for condemning a food crop found to be contaminated."

From all this it will be clear that it is much easier to sell herbicides in Great Britain than it is in the U.S.A. Before long I am sure that we will have to take a firmer line, but the British seem to have an inherent reluctance to drawing up any more laws and regulations than are absolutely essential. We believe that this freedom from the red tape of restriction and the consequent sharing of responsibility between the State and Commerce makes it possible for more effort and money to be devoted to constructive and original work.

One of the consequences of the absence of any strict control by the State is that chemical manufacturers and merchants carry out most of their own development work on new herbicides and do not rely on the State. Most of the large companies in Great Britain have their own research stations and carry their field trials through to the stage where they can make their own recommendations to the farmer and the horticulturist. We have no arrangement, as exists in many other European countries, for the official testing of proprietary products. True, we have an "approvals scheme" operated by the Ministry of Agriculture for the vetting of labels of proprietary products, but again this is a *voluntary* scheme and the approval is based mainly on evidence submitted by the vendor of the product. The result is that the National Agricultural Advisory Service is often not in a position to give advice concerning the use of proprietary products, for not only have these products not been tested by official research stations, but sometimes neither the nature nor the quantity of the active ingredient is disclosed. So it is that manufacturers and merchants take on many of the Advisory activities which in other countries are considered to be the prerogative of the State.

If such a system of partnership between the State and Industry is to work, there is a need for close liaison and mutual trust. This is accomplished not by official committees and co-ordinating bodies,

but by arrangements for informal liaison mainly through "The British Weed Control Council."

THE BRITISH WEED CONTROL COUNCIL

This Council was formed in 1953. It is composed of representatives from all organisations interested in weed control and includes members from the Ministry, the Agricultural Research Council, the Advisory Services, the National Farmers' Union, Learned Societies, Industry and Commerce. It has no official status, but provides for all a forum for the discussion of the many diverse problems created by the rapid expansion in the use of herbicides.

The Council organises National Weed Control Conferences and arranges for scientific symposia on special aspects of weed control. It distributes "Weed Abstracts" and its Recommendations Committee produces the Weed Control Handbook, the accepted guide to the use of herbicides in Great Britain.

CONCLUSION

Thus we seem to have evolved a system which gives the maximum degree of freedom to chemical manufacturers and merchants while at the same time safeguarding the interests of the user and general public. Since the war, much of the research and development has been undertaken by the larger chemical firms. They have spent very large sums of money synthesising and screening new chemicals, in testing them out in the field and advising the user. This will continue in the future, but as herbicides become more specialised in their application and as it becomes ever more necessary to consider them as an integral part of Crop Husbandry, to be combined with cultural methods in the evolution of different and novel techniques, so will it become necessary for the State to take a more positive part in the research and advisory duties connected with this subject.

A Conference Was Born[1]

WALTER S. BALL[2]

IT gives me a great deal of pleasure to have been asked to talk on the subject, "A Conference Was Born". Before going into the birth of the first conference I would like to give some history which had much to do with the first weed control conference.

It so happened that I was involved with the Western Plant Quarantine Board in the early 1930's, inasmuch as they had become very much interested in weed control—primarily from the quarantine viewpoint. The Western Plant Quarantine Board had been passing resolutions requesting federal assistance for more research and education for the control of noxious weeds in the West.

Little attention was given to the resolutions until about 1936 at a meeting in Boise, Idaho. The officers of the Western Plant Quarantine Board contacted other regional boards for the purpose of establishing a national weed committee to work toward a national program of noxious weed control. In this the Western Board was successful, and a national weed committee was appointed with one member from each of the four regions which constitute the National Plant Quarantine Board. Two regional meetings were held, out of which came two very definite things.

First was the movement for research funds for the United States Bureau of Plant Industry and it was largely through the efforts of the people in the central states cooperating with the weed committee of the Western Plant Quarantine Board that the first Federal research work on noxious weeds was inaugurated. Secondly, out of the Central Weed Committee came the first suggested national weed program, which had been under discussion for several years. It has been the basis upon which was formed the national program under the National Weed Committee. The Eastern and Southern Boards did not appear to be greatly interested in this movement.

It was due to the insistence of the western states that a national program of weed control was organized at an annual meeting of the American Federation of Farm Bureaus. The American Federation passed this resolution:

> "Recognizing the alarming increase in noxious weeds as one of the greatest problems, we recommend that Triple A continue weed control and that the Federal Government extend reasonable cooperation to and provide for cooperation and coordination in the use of approved methods for weed eradication."

Following this action, the executive committee members of the American Federation of Farm Bureaus endorsed the Clark Bill. Representative Clark from Idaho presented a bill in Congress for an appropriation of 25 million dollars—primarily for research and edu-

[1]Presented at joint meeting of the Weed Society of America and the Western Weed Control Conference, Denver, Colorado, February 22–25, 1960.

[2]Chief, Bureau of Rodent and Weed Control and Seed Inspection, California Department of Agriculture.

cation. The National Weed Committee felt that this amount was too great and asked Representative Clark to reduce the amount to 5 million dollars.

It might be of interest to note that Henry A. Wallace, Secretary of Agriculture at that time, wrote a four page letter to Marvin Jones, Chairman, Committee of Agriculture, House of Representatives. The first paragraph of the letter stated that reference was made to his letter of February 4 requesting a report from his committee on House of Representatives Bill 9313 by Mr. Clark of Idaho:

> "To provide for the general welfare by establishing a system of federal benefits and by enabling the several states to make more adequate provision for the control and eradication of noxious weeds; to conserve and protect the natural resources of the several states of the United States; to empower the Secretary of Agriculture to make certain rules and regulations; prescribe conditions to raise revenues, and for other purposes."

In this letter the Secretary mentioned that methods of weed control varied between the states and said that the control of the Department over effective operations was limited. He did not concur with the definition of noxious weeds by states. The final statement in the Secretary's letter was that, for the above reasons, the Department did not approve the House of Representatives Bill 9313.

It was the interest of the Western Plant Quarantine Board in weed control that had much to do with the formation of the first conference.

I was requested to attend a meeting at Salem, Oregon in 1937 where Professor George Hyslop from Corvallis, Oregon, and Harry Spence from Idaho were present. We had an opportunity one evening to discuss this entire program and we felt that weed control was important enough to the eleven western states that they should organize and take the burden of carrying on the work which the Western Plant Quarantine Board had initiated.

So, on Thursday morning, June 16, 1938, the Western Weed Control Conference was born.

There were some 27 persons present. Mr. Harry Spence of Idaho, who was acting chairman, was elected president and I was made secretary. Our conference met annually in different states throughout the eleven western states.

Later I had the pleasure of being invited to a meeting in Nebraska with representatives from regulatory staffs of Kansas, Nebraska and Minnesota; the research and extension departments of the University of Minnesota and one representative from Industry. It was at this meeting that the organization of the North Central Weed Conference was discussed. Later I had the pleasure of attending the organization meeting of the North Central Weed Conference in Omaha, Nebraska in 1944.

The Northeastern Weed Control Conference was organized at Cornell University in 1947. Present at this meeting were representatives from research, extension and industry. I also had the pleasure of attending their first conference.

The Southern Weed Conference was organized in 1948 at Stoneville, Mississippi, and was made up of representatives from research, industry and extension. I did not meet with this conference on their organizational meeting, but I met with them later.

Following the organization of the various conferences, it was suggested that there should properly be a national organization to coordinate the conferences. It was decided that there should be a meeting of representatives from each of the four conferences. This organization was known as the Association of Regional Weed Control Conferences. At the first meeting the following representatives from the various conferences were present:

E. C. Tullis, of Texas, Southern Conference
H. L. Howell of Esso Laboratories Chemical Division, Lisbon, New Jersey, Northeastern Conference
R. S. Dunham, of the Department of Agronomy, University of Minnesota, St. Paul, North Central Conference
L. W. Kephart of Maryland, representing the USDA, and I was present to represent the Western conference.

At this meeting the organization, membership, etc., was discussed.

The second meeting of the organization was held in Kansas City in May 1950. The third meeting was held in Memphis, Tennessee in 1951 and at this meeting eight representatives were present. The fourth meeting was held in Washington, D. C. in 1952 and the fifth in Kansas City, Missouri in 1953.

The sixth meeting of the Association of Regional Weed Control Conferences was held in Fargo, North Dakota in 1954. It was at this meeting that a constitution was adopted as a temporary constitution for the Weed Society of America. It was decided that this temporary constitution should serve until the time of the charter meeting in New York City, January 1956.

In 1956 the Weed Society of America was born.

It is of interest to those of us who had a part in weed control conferences that our Canadian friends to the north had organized weed conferences, both provincial and national.

It is also of interest to note that many state weed conferences have been organized and are active. I can speak more specifically about the California Weed Conference which held its 12th annual meeting in Sacramento last month. Our California weed work has gained a great deal of popularity and our attendance annually has been even greater than our Western Weed Control Conference.

Other states have either weed meetings or weed conferences which do much toward better understanding and, consequently, better weed control programs.

I recall a statement made by Dr. R. S. Dunham, Minnesota, back in 1953 when we held our first National Weed Control Conference in Kansas City, Missouri: "It is indeed encouraging that the cooperation between regulatory, educational, and research agencies, both public and private, insures best results in weed control practices. The capacity to work together demonstrated by weed conferences is cause for real encouragement."

Growth of Witchweed *(Striga asiatica)* as Affected by Soil Types and Soil and Air Temperatures

E. L. Robinson[1]

Witchweed *(Striga asiatica)*, a parasitic plant with brilliant-red flowers and hairy bright-green stems and leaves, was identified in the Western Hemisphere for the first time in 1956 (2), although it had been present in the United States for several years. Figure 1

Figure 1. Corn at Whiteville, North Carolina, affected by witchweed.

shows severe corn damage caused by witchweed. In a 1959 survey conducted by the United States Department of Agriculture witchweed was found on approximately 250,000 acres of land in 15 counties in North Carolina and 7 counties in South Carolina. It attacks many species in the family Gramineae (1, 4, 5, 8). Witchweed jeopardizes the production of corn, sorghum, sugarcane, and probably other gramineous crops in any climatological regions of the United States where it may be adapted. This study attempted to obtain some indication of the possible limits of its spread.

[1]Agronomist, Crops Research Division, Agricultural Research Service, United States Department of Agriculture, in cooperation with the Plant Pest Control Division and the North Carolina Agricultural Experiment Station, Whiteville, North Carolina.

LITERATURE REVIEW

Two factors that influence the geographical distribution of witchweed are soil temperature and soil type. According to Jones (4) approximately 50 species of witchweed have been known for many years, but only within the last 50 years has their serious nature been appreciated. The published papers generally indicate that witchweed species favor the lighter, sandier soils.

Saunders (9) indicated that in South Africa the infestation of witchweed is heaviest in regions with 18 to 25 inches of rainfall and on soils of the lighter types. Hattingh (3) also reported that witchweed is found chiefly on sandy and light loam soils. On the other hand, numerous reports from various investigators indicate the presence of witchweed on heavier soils. Nelson (7) conducted greenhouse work on 8 soil types. Witchweed germinated and became established on soils ranging through sands, loams, peat, and light clay. However, it failed to become established on a heavy clay loam. Nelson (7) showed that witchweed would germinate at approximately 65° F. in light sandy soil, but for witchweed to germinate in light clay the temperature had to be approximately 90°, so there are important interrelationships between soil type and temperature in the germination of witchweed. The optimum temperature for witchweed germination seems to be near 90°, the maximum about 104°, and the minimum approximately 65° (1, 6, 9). Soil temperatures and soil types are so interrelated that any discussion of the germination of witchweed must include both factors.

METHODS AND MATERIALS

Soil types were obtained from a number of states in the South and Midwest and tested under field conditions at Whiteville for their effectiveness in supporting the growth of witchweed. They were Cecil silt loam from Georgia, Bosket very fine sandy loam and Kaufman clay from Mississippi, Mhoon sandy clay loam and Sharkey clay from Louisiana, Okeelanta peaty muck and Delray fine sand from the sugarcane area of Florida, Lakeland sand and Norfolk sandy loam from North Carolina, Miami silt loam from Ohio, a heavy silt loam of the Chamber series from Indiana, and Webster silty clay loam from Iowa.

The soils were placed in 2 by 2 by 1 foot 24 gauge metal boxes with open bottoms. The soils were 8 to 10 inches deep in each box as witchweed has never been observed to emerge from a depth greater than 5 inches. The boxes of soils were randomized and replicated three times.

The various soil types were inoculated by thoroughly mixing the soil in each box with ½ pint of soil heavily infested with witchweed. Corn was used as the host plant and as the two grains of corn were planted per box, each grain of corn was dusted with approximately 50 witchweed seeds. An application of 5–10–10 fertilizer at the rate of 600 pounds per acre was thoroughly mixed into the top 2 inches of each box of soil. The experimental boxes were

hand weeded when necessary. Tests were conducted during the growing seasons of 1957 and 1958. The soils, except Kaufman clay, were not re-inoculated with witchweed seed in 1958.

An instrument house was placed on an area of Lakeland sand at Whiteville. Three thermographs recorded soil temperature at various levels and a hygrothermograph recorded air temperature and relative humidity.

RESULTS AND DISCUSSION

Witchweed germinated and grew vigorously on all soil types included in the studies during the 1957 and 1958 growing season at Whiteville, North Carolina except one. Figure 2 shows witchweed

Figure 2. Witchweed on corn growing in Norfolk sandy loam soil in soil type study at Whiteville, North Carolina.

growing on corn in Norfolk sandy loam soil. In Kaufman clay from Mississippi, witchweed failed to grow above ground in 1957. However this same soil reseeded with witchweed and retested in 1958 grew witchweed to maturity and many thousands of seeds were formed. Apparently the structure of the heavy clay was gradually broken down when removed from natural conditions and placed in the metal containers, thereby providing a suitable environment for the growth of witchweed.

The soil and air temperatures have been averaged and shown on bar graphs (Figures 3A, 3B, 3C). These bar graphs have been compared to temperatures of a witchweed infested area in Africa[2] (Figure

[2]Anonymous. Answers to United States Embassy Questionaire—1956. Temperatures taken at the College of Agriculture, Potchefstroom, South Africa.

3D) and of a non-infested area at Lincoln, Nebraska (11) (Figures 4A, 4B). A line was drawn on the bar graphs at 70 degrees Fahrenheit, to represent a near-minimum temperature for witchweed germination. The time required for witchweed to complete its life cycle has been found by the author and other workers to be 90 to 120 days. Length of the period depends on various environmental factors.

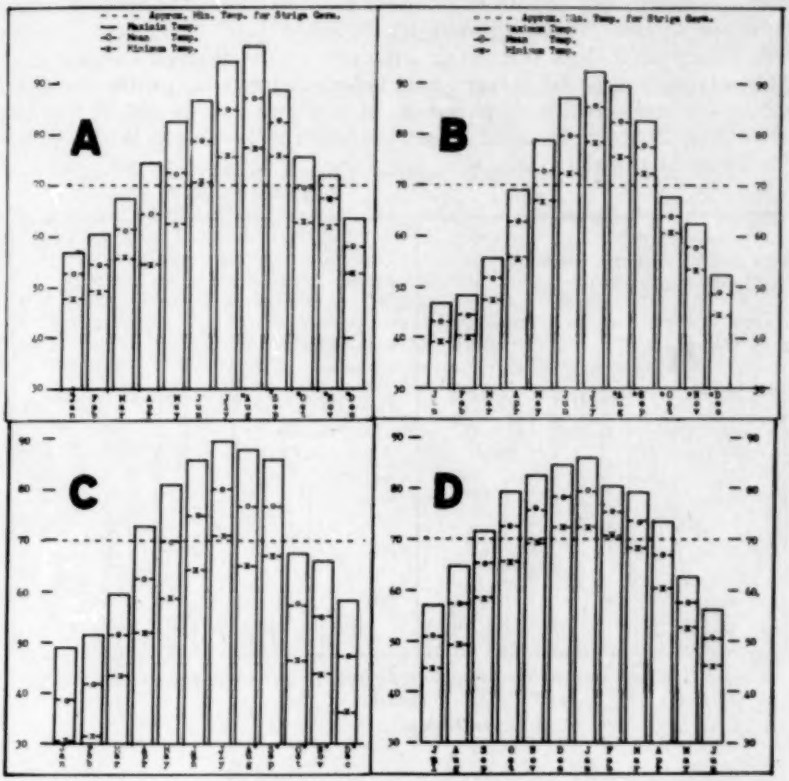

Figure 3. Monthly average maximum (top of bars) mean (–o–) and minimum (–x–) temperatures, in degrees F.:

A. At Whiteville, North Carolina, in soil, 3-inch depth.
B. At Whiteville, North Carolina, in soil, 6-inch depth.
C. At Whiteville, North Carolina, in air. (All from Aug. 1957 thru July 1958.)
D. At College of Agriculture, Potchefstroom, South Africa, 9-year averages in soil at 2-inch depth.

On Figures 3A, 3B, and 3C it can be noted that the average soil and air temperature at Whiteville, North Carolina was 70° F. or more for at least 150 days. In Figure 3A the soil temperature at the 3-inch level, where most witchweed appears to germinate, was 70° F. or more for approximately 180 days. In Potchefstroom, South Africa

(Figure 3D) the temperature at the 2-inch soil depth was 70 degrees for approximately the same number of days. The fact that the annual rainfall in Potchefstroom is less than ½ of the annual rainfall of Whiteville, but their temperatures are approximately the same, suggests that temperature may be more important than rainfall in determining areas in which witchweed will grow well.

In Figure 4B the soil at Lincoln, Nebraska at the 3-inch depth had a temperature of 70° F. or more for 120 days. This is sufficient time for witchweed to complete its life cycle, but all germination of witchweed seed does not occur precisely at 70 degrees Fahrenheit. Many factors must be investigated before any evaluation of the germination and possible distribution of this pest can be made, but its growth at Lincoln, Nebraska does not seem to be precluded by what we know at present.

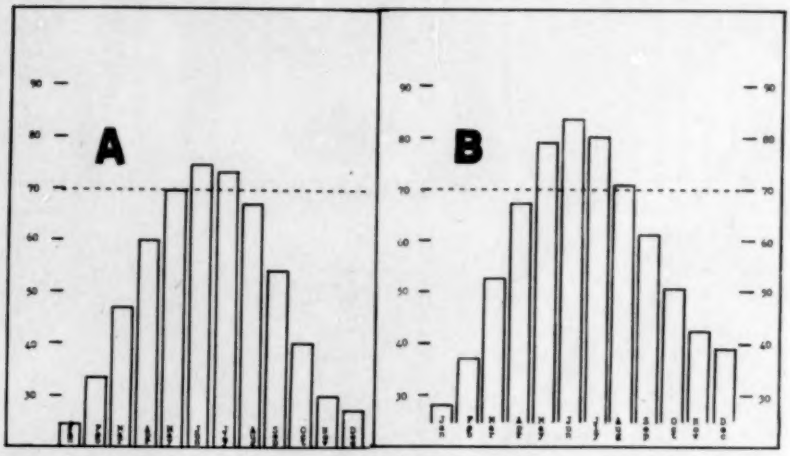

Figure 4. Mean monthly temperatures, degrees F., 12-year averages, at Lincoln, Nebraska.

A. In air. B. In soil, 3-inch depth.

SUMMARY

The germination and growth of witchweed was evaluated on 12 soil types placed under field conditions at Whiteville, North Carolina in 1957 and 1958. The soil types were from the southern and midwestern United States and ranged in texture from a coarse sand to a heavy clay, with one organic soil. Witchweed germinated and grew well on all soil types investigated except Kaufman clay in 1957. It grew well on all soil types, including Kaufman clay, in 1958.

The soil temperatures near Whiteville, North Carolina, are very similar to soil temperatures in an area in which witchweed grows indigenously at Potchefstroom, South Africa. The general trend of temperatures at Lincoln, Nebraska is lower than the temperatures at Whiteville, North Carolina, but from these data it would be

difficult to be sure that witchweed would not survive at Lincoln, Nebraska. It would appear improbable that temperature alone will be a permanent barrier to the further spread of witchweed in the United States.

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Effect of Temperature on the Herbicidal Activity and Translocation of Arsenicals[1, 2]

CHARLES B. RUMBURG,[3] RALPH E. ENGEL, and WILLIAM F. MEGGITT

ARSENIC-CONTAINING compounds have been widely used in the field of weed control. Sodium arsenite has been employed for general contact weed control, and as a herbicide on turf areas. In the latter capacity it is used to control undesirable species without inflicting severe or permanent injury to desirable turf grasses. Disodium methylarsonate (DMA) and dimethylarsinic acid (cacodylic acid) have more recently been shown to possess herbicidal properties. DMA has been used for the selective control of crabgrass in turf, and for removal of certain weedy species from Bermudagrass.

Cacodylic acid has shown promise for the complete removal of established sod for the purpose of renovation.[4] It seems to be particularly well suited for this purpose in that it apparently leaves no residues that will interfere with the subsequent establishment of the seedlings.

REVIEW OF LITERATURE

Bermudagrass and other species have been reported as being quite tolerant to DMA (1, 2, 8); however, there is generally a very narrow range in rate of application between satisfactory weed control and injury to desirable species when arsenical herbicides are used (6, 7, 12). Consequently, any environmental factor that affects the herbicidal activity will be of utmost importance in the application of these chemicals. Gallagher (9) reported that several workers have found DMA to be more active when applied during periods of high temperature. Musser (13) indicated that sodium arsenite results in more injury to turf grasses under conditions of high temperature and low soil moisture. No information was available regarding the effect of temperature on the phytotoxicity of cacodylic acid.

Studies of the absorption and translocation of arsenicals have been limited to the inorganic arsenicals, sodium arsenite in particular. Sodium arsenite will move downward to some extent when applied to the foliage of plants as an acid arsenical solution (3, 4, 10). It is also known to move upward in the xylem of ringed trees (15).

The effect of temperature on the translocation of foliar applied

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[1]Paper of the Journal Series, Department of Farm Crops, Rutgers. The State University, New Brunswick, New Jersey.

[2]This paper is based upon a thesis prepared by the senior author in partial fulfillment of the requirements for the Ph.D. degree at Rutgers University. The study was financed in part by a grant from the American Smelting and Refining Company, South Plainfield, New Jersey.

[3]Present address: Squaw Butte-Harney Experiment Station, Agricultural Research Service, U. S. Department of Agriculture, Burns, Oregon.

[4]Evrard, T. O. Some of the agronomic aspects of pasture renovation with herbicides. M.S. Thesis. Rutgers University. 1958.

nutrients and herbicides has been previously studied. Although no arsenicals have been included in these studies, it has generally been found that an increase in temperature, within limits, results in increased penetration (5, 14).

MATERIALS AND METHODS

These studies were conducted in controlled environment chambers at the New Jersey Agricultural Experiment Station. Temperature control was maintained in the environment chambers by an air conditioner cooling against the heat from the lights, the heaters, or both. Strip heaters were necessary to provide heat when the lights were off. In this manner the temperature was controlled within a range of ±3° F. with a 3° F. gradient across the chambers. Night temperatures averaged about 4° F. cooler than day temperatures, due to a heating effect of the lights on the exhaust side of the thermostat bulb. The relative humidity at 60° F. was approximately 15 percent higher than at 90° F. The plants received 1,000 foot-candles of light for 12.5 hours supplied by sixteen 96-watt, cool-white fluorescent tubes.

Crabgrass *(Digitaria sanguinalis)* was selected as the test species. Four plants were grown per pot and treated when the main culm was 10 to 12 inches high, with 3 to 4 tillers on each plant. The plants were grown in the greenhouse and placed in temperature control chambers after application of the herbicides. The selected temperature was maintained constant for the duration of the experiment. All replications of one rate were sprayed simultaneously and placed in the chambers within 3 minutes after treatment.

In the experiments conducted at 60, 75, and 85° F. four rates of each herbicide were used and there were 8 replications of each treatment at each temperature. The rates of application were as follows: DMA at 0, 2, 6, and 18 lb/A; cacodylic acid at 0, 1, 3, and 9 lb/A; and sodium arsenite (on the basis of As_2O_3) at 0, 0.5, 1.5, and 4.5 lb/A. The plants were harvested 10 days after treatment. Temperatures were separated in time as well as in space and replications at one temperature were not directly related to replications at another temperature. An analysis of variance was conducted for each temperature, the weights were then converted to a percent of control, and an analysis of variance was conducted on transformed percentage data combined among temperatures.

In the frequency of application experiment, the total rate of application of DMA, cacodylic acid, and sodium arsenite was 20, 12, and 2 pounds of active ingredient per acre respectively, at constant temperatures of 60 and 90° F. One series of plants received one-fourth the total rate on the first, third, fifth, and seventh day; another received half the total rate on the first and fourth day; and the third treatment received the total amount applied in one application on the first day. The plants were harvested 11 days after the first treatment.

In another series of tests translocation was studied by using

arsenic–76.[5] The sample of DMA–As^{76} used in these experiments contained 100 mg of DMA per ml with a specific activity of approximately 100 microcuries per ml. The sodium arsenite solution contained 50 mg of sodium arsenite (approximately 4 As_2O_3 : 3NaOH) per ml with a specific activity of about 100 microcuries per ml.

Soybeans (*Glycine max* var. Clark) and crabgrass were grown in Nixon loam soil mixed 1:3 with sand. The soybeans were grown outside and the crabgrass inside the greenhouse.

At the time of treatment the first trifoliolate leaf of the soybeans was fully expanded, and crabgrass had four leaves on the main culm and was approximately 5 inches tall. Plants were preconditioned to the experimental temperature of either 85 or 60° F. for 3 hours prior to treatment. A 0.05-ml drop of the radioactive preparation was applied to one of the primary leaves of soybeans, and to the second leaf below the terminal leaf on crabgrass.

To assay for activity the plants were cut off at the soil surface, sectioned directly into planchets, and dried in an oven at 80° C. The soybeans were sectioned into the following parts: a) treated leaf, b) the other primary leaf plus the internode and trifoliolate leaf, and c) that portion of the stem below the treated leaf. The crabgrass was sectioned into two parts, the treated leaf and the remainder of the aboveground portion. All treatments were conducted in duplicate.

The assay for As^{76} was accomplished with a G–M end window counter and a Nuclear Autoscaler. All samples were corrected for background, and since they were counted within a few minutes of each other no corrections were made for decay. Counting rates above 10,000 cpm were corrected for coincidence loss (4).

RESULTS

Crabgrass injury, resulting from treatment with DMA at 60, 75, and 85° F. and from 3 frequencies of application at 60 and 90° F., was based on contact injury, chlorosis, and the reduction in dry weight.

Using the reduction in dry weight as an indication of herbicidal activity, there was a significant reduction in dry weight with an increase in temperature (Table 1). Increasing rates of DMA also produced significant reductions in total growth.

Table 1. The effect of temperature following treatment on the activity of DMA as indicated by dry weight of crabgrass 10 days after application.

DMA lb/A	Dry weight, per cent of control			Mean
	60° F	75° F	85° F	
2	89	82	80	84
6	80	69	58	69
18	72	58	42	57
Mean	80	70	60	—

LSD for temperature and rate mean: .05 = 8; .01 = 11.

[5] Radioactive samples of DMA and sodium arsenite were prepared by New England Nuclear Corp., Boston, Mass.

Ten days after treatment with DMA, contact injury ratings did not show any appreciable difference among experiments conducted at 60, 75, and 85°F. (Table 2). However, the contact injury increased with increasing concentrations of the herbicide.

Table 2. The effect of temperature after treatment on contact injury produced by DMA as indicated by injury ratings on crabgrass 10 days after application.

DMA lb/A	Injury ratings[a]			Mean
	60° F	75° F	85° F	
2	1.6	2.2	1.7	1.8
6	3.5	3.9	3.2	3.5
8	5.8	5.0	5.0	5.3
Mean	3.6	3.7	3.3	—

[a]Injury ratings were made from 0 to 10 (0 = no injury and 10 = complete kill) by two individuals

Chlorosis increased with increasing temperatures (Table 3). The chlorosis at 60° F. did not differ significantly among rates of application, but at 75 and 85° F. the amount of chlorosis was dependent on rate, although there was little difference between the 6 and 18

Table 3. The effect of temperature after treatment on the degree of chlorosis induced by DMA as indicated by ratings on crabgrass 5 and 10 days after application.

DMA lb/A	Chlorosis rating[a]					
	60° F		75° F		85° F	
	5 days	10 days	5 days	10 days	5 days	10 days
2	0.2	2.7	3.2	2.2	1.8	2.0
6	0.2	3.3	6.8	6.0	5.1	7.1
18	0.3	2.7	7.1	7.1	5.4	7.6
Mean	0.2	2.9	5.7	5.1	4.1	5.6

[a]Chlorosis ratings were made from 0 to 10 (0 = no chlorosis and 10 = complete chlorosis) by two individuals.

lb/A rate. An increase in temperature also appeared to increase the rate of development of the chlorosis. At 60° F. the loss of chlorophyll was hardly noticeable 5 days after treatment; but at 75 and 85° F. loss of chlorophyll became evident 2 to 3 days after treatment, and had generally reached a maximum by the fifth day.

The frequency-of-application experiment conducted at 60 and 90° F. again showed a greater activity from DMA at the higher temperature (Table 4). The data indicate that variation in the time and rate of treatment with 20 lb/A of DMA had little effect on the herbicidal activity at 90° F. However, the values at 60° F. show a tendency toward greater injury with a single application of 20 lb/A than the same total amount applied in multiple applications. The interaction was not statistically significant, but a difference of this kind might be expected if temperature affects herbicidal activity.

Table 4. The effect of frequency of application of DMA on injury to crabgrass at two temperatures as indicated by dry weight.

DMA		Dry weight, per cent of control		
Number applications	Rate, lb/A each application	60° F	90° F	Mean
4	5	75	49	62
2	10	72	49	60
1	20	66	50	58
Mean		71*	49	NS

*Significantly higher at .01 level.

Similar experiments were undertaken with cacodylic acid and sodium arsenite. No consistent trends indicated that temperature following treatment had any effect on the herbicidal activity of cacodylic acid or sodium arsenite.

Studies of the translocation of arsenic were conducted primarily to measure the relative movement of arsenic as DMA at 85° F. with that at 60° F. Translocation of arsenic was evident in soybean plants 6 hours after treatment (Table 5). There was greater translocation

Table 5. Activity found in sections of soybean plant 6 hours after treatment with 5 mg of DMA–As^{76} at 85 and 60° F.

Section of plant	60° F		85° F	
	Activity cpm	Per cent recovered activity	Activity cpm	Per cent recovered activity
Trifoliolate plus one primary leaf. . .	132	0.19	419	0.74
Stem below the treated leaf.	428	0.61	618	1.07
Treated leaf.	70,000	99.2	57,000	98.2

at 85 than at 60° F. There was also more activity in the stem below the treated leaf than there was in the other primary leaf plus the internode and trifoliolate leaf above the treated leaf.

Autoradiograms of soybean plants (not included) substantiated the data in Table 5. There was more activity distributed throughout the entire plant in those plants held at 85° F. than in those held at 60° F. The plants were dried between blotters in an oven and some of the activity may have been the result of movement during drying; however, the relative comparison between the two temperatures should be valid.

Crabgrass plants harvested 5 hours after treatment had more activity in the untreated foliage at 85° than at 60° F. The actual amount of activity was 3,154 cpm at 85° F. and 1,382 cpm at 60° F., which was 1.2 and 0.5 percent, respectively, of the recovered activity.

Soybeans treated with 2.5 mg of sodium arsenite–As^{76} were held at 85° F. for 8 hours following treatment. The activity recovered in the untreated portions of the foliage indicated that the arsenic was translocated to a limited extent (Table 6). The actual distribution

Table 6. Activity found in sections of soybean plant 8 hours after treatment with 2.5 mg of sodium arsenite–As^{76} at 85° F.

Section of plant	Mean activity cpm	Per cent recovered activity
Trifoliolate plus one primary leaf	169	0.10
Stem below the treated leaf	960	0.57
Treated leaf	166,000	99.32

of the activity did not differ appreciably from that found with DMA 6 hours after treatment. However, when expressed as a percent of the recovered activity the translocation of arsenic applied as sodium arsenite appeared to be substantially lower than the movement of arsenic applied as DMA. Approximately 85 percent of the total activity applied as sodium arsenite was recovered in the foliage of soybean plants and only 30 to 40 percent of the total activity applied as DMA was recovered.

DISCUSSION

The greater movement of arsenic applied as DMA at higher temperatures may be partially responsible for the more rapid response of crabgrass to DMA at higher temperatures. However, cool temperatures (around 60° F.) appeared to reduce the overall effectiveness of DMA on crabgrass.

It was not possible to arrive at any conclusions regarding the effect of temperature on the herbicidal activity of sodium arsenite or cacodylic acid. In the case of sodium arsenite this is perhaps not surprising, considering that the arsenites can inhibit a wide range of enzymes by the formation of thioarsenites. This reaction is apparently quite rapid. The mode of action of cacodylic acid, as with DMA, is unknown.

Arsenic, applied as DMA, appeared to be more mobile in soybean plants than arsenic applied as sodium arsenite. A much larger percentage of the total activity applied as sodium arsenite was recovered in the above-ground portion 8 hours after treatment than was possible for DMA 6 hours after treatment. The activity that was unaccounted for in the case of DMA was presumably lost in the roots, but this was not measured. Autoradiograms showed activity in the roots of soybean plants held at 85 and 60° F. after treatment. There was more activity in those held at 85° F. than in those held at 60° F, but it is difficult to say how much of the movement at either temperature was due to movement of the isotope during the drying process.

Plant tissue treated with DMA does not show visible symptoms of injury for some hours or even days after treatment, which offers a greater opportunity for DMA to be translocated through normal plant processes. Sodium arsenite, on the other hand, will often result in localized injury symptoms, such as loss of turgidity, within a few hours after treatment.

SUMMARY

The effect of temperature after treatment on the phytotoxicity of disodium methylarsonate (DMA), dimethylarsinic acid (cacodylic acid), and sodium arsenite was studied in controlled temperature chambers using crabgrass as a test plant. The translocation of arsenic applied as DMA tagged with As^{76} was measured at 85 and 60° F. and the translocation of arsenic applied as sodium arsenite–As^{76} was measured in soybeans at 85° F.

The phytotoxicity of DMA to crabgrass increased with increasing temperatures. The chlorosis caused by the chemical increased in severity and speed of appearance with increasing temperatures. The contact injury was relatively constant among temperatures.

There were no consistent trends that would indicate temperature after treatment had any effect on the herbicidal activity of either sodium arsenite or cacodylic acid.

Arsenic, applied as DMA–As^{76} to a leaf of both soybeans and crabgrass, was found to translocate to a greater extent in both species at 85° F. than at 60° F. Arsenic applied as sodium arsenite–As^{76} was also found to translocate in soybeans. The data suggest that arsenic applied as DMA was more mobile than arsenic applied as sodium arsenite.

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The Effects of Four Herbicides on Microorganisms in Nine Oregon Soils[1]

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THE potential extensive use of certain new herbicides has made it desirable to study their effects on soil microorganisms. If these compounds have any retarding or stimulating influences on the general soil microflora, this could be reflected in carbon dioxide evolution during soil respiration experiments. Microorganisms are important to soil fertility because they transform potential plant nutrients into active or available forms, and carbon dioxide is a significant index of their activity. The effects on carbon dioxide evolution of four new herbicides that have shown promising results in field trials at this station (1) are presented in this report.

REVIEW OF LITERATURE

A review of the effects of herbicides on microorganisms and microbial processes has been given by Newman and Downing (9). Most of the literature on this subject deals with 2,4–dichlorophenoxyacetic acid (2,4–D) and related compounds. Normal rates of treatment appear non-injurious to soil microorganisms, although in some cases carbon dioxide evolution may be depressed, and very high rates inhibit nitrification. Certain herbicides, especially hormone types, disappear from the soil in many cases due to microbial decomposition. Soil type as well as environmental conditions are controlling factors in these phenomena. Kind and amounts of organic matter and clay may be especially important. Thus, Dallyn (7) observed that the response of sweet corn and red beets to 3–(*p*–chlorophenyl)–1,1–dimethylurea (monuron) and sodium 2,4–dichlorophenoxyethyl sulfate (sesone) was influenced by the level of soil organic matter, yields being greater at higher organic matter contents. A similar interaction was not observed with 2,4–D or with 2,4–dichlorophenoxyethyl benzoate (sesin). Bingham and Church (3) found that high organic matter and high clay content do not decrease the toxicity of 3–(3,4–dichlorophenyl)–1,1–dimethylurea (diuron), while pH, nitrogen and potassium do influence it. It is thus evident that organic matter ameliorates the toxicity of certain herbicides, whereas the influence of clay is variable and probably dependent upon the kind of clay, especially whether kaolinitic or montmorillonitic. An extensive bibliography of the fate and decomposition of organic weedkillers has been prepared by the Commonwealth Bureau of Soil Science in England (6). Although results of studies on the influence of many

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herbicides on microbial properties of the soil have been published, no investigations on the effects of 2,3,6–trichlorobenzoic acid (2,3,6–TBA), ethyl N,N–di–*n*–propylthiolcarbamate (EPTC), diuron, and 2–chloro–4,6–bis(ethylamino)–*s*–triazine (simazine) on the general soil microflora and carbon dioxide evolution have been reported. However, Reid (12) determined that simazine and 3–amino–1,2,4–triazole (amitrole) only temporarily interfered with nitrification and that the compounds were subsequently destroyed by soil diphtheroids.

MATERIALS AND METHODS

Nine soil samples taken to a depth of seven inches, representing a wide range of parent materials and locations in Oregon, were used. They were air dried, screened through a 2 mm sieve and stored in polyethylene cartons for subsequent use. The soils were characterized for pedological, chemical and physical properties, as shown in Table 1.[5]

Moisture capacity, or water held against gravity, was calculated from the amount of water retained by samples in Gooch crucibles wetted from below by immersion and then allowed to drain to constant weight in a moisture saturated atmosphere. Fifty per cent of this value was used in incubation; this expressed on the oven-dry basis corresponds approximately to field capacity or from one-third to one-half atmosphere moisture tension.

Clay content was determined by the Kilmer and Alexander (8) method.

For pH, a soil water ratio of 1:5 was used. Ten grams of soil, water-free basis, and 50 ml distilled water were stirred in a 100 ml beaker and after coarse particles had settled, readings were made with a Model N Beckman pH meter and glass electrode. Lime requirement was determined by the Woodruff method (15).

Cation exchange capacity was determined by the ammonium acetate method of Schollenberger and Simon (13).

Organic matter was estimated by the Walkley and Black method (14). To establish the carbon-to-nitrogen ratio (C:N), Kjeldahl nitrogen was determined by the AOAC method (2).

Herbicides. 2,3,6–TBA, EPTC, diuron and simazin were used in concentrations to give 5 and 100 ppm active ingredients in the soil. The 100 ppm rate is from 20 to 35 times the normal rate in field practice. Uniform suspensions were applied in cases where the solubility in cold water was limiting.

Carbon dioxide evolution studies. One hundred gram portions of soil, oven-dry basis, were used in pint milk bottles. Comparison of the moisture with moisture capacity for each soil as shown in Table 1 indicates that the samples, although air-dried, still retained an

[5]Samples were collected by Mr. T. T. Chao for studies on relationship of soil properties to chemical reactions and other phenomena involving sulfur. Appreciation is expressed to T. T. Chao, M. E. Harward and S. C. Fang, Oregon Agricultural Experiment Station, for permitting use of pertinent supplemental data in Table 1.

Table 1. Pedological, physical and chemical characteristics of soil.

Soil series[a] and class	Parent material[a]	Great soil group[c]	Clay[b] pct	Moisture relations		pH	Woodruff lime requirement[b] tons/A	Organic matter[b] pct	C:N ratio	Cation exchange capacity[b] me/100 gm
				Moisture pct	Moisture capacity pct					
Deschutes sandy loam	Pumice	Regosol	8.1	3.7	27.0	6.3	0.5	1.57	11.4	9.69
Medford[d] sandy loam	Old Alluvium	Prairie	10.2	4.2	29.5	6.0	1.0	3.33	16.2	11.60
Walla Walla silt loam (cultivated)	Loess	Chestnut	15.7	9.9	31.8	6.4	1.0	2.24	14.4	17.61
Chehalis loam	Recent Alluvium	Alluvial	18.3	4.4	38.1	5.8	1.0	2.19	12.7	21.00
Wingville loam	Recent Alluvium	Humic Gley	25.1	4.8	47.7	8.4	—	7.54	12.9	23.38
Knappa loam	Old silty Alluvium	Brown latosol	25.1	12.6	52.5	6.2	4.5	18.32	14.3	61.58
Walla Walla clay loam (virgin)	Loess	Chestnut	29.1	4.9	40.6	6.9	0.5	2.28	10.2	18.78
Astoria silty clay loam	Sedimentary rock residium	Brown latosol	30.9	5.8	45.1	5.3	5.5	12.80	17.7	34.59
Aiken[d] clay	Basalt residium	Reddish brown latosol	57.7	5.3	37.0	5.5	3.5	6.83	15.9	26.72

[a]Samples collected by Mr. T. T. Chao, Soils Department, except Walla Walla soils by M. M. Ovenson, Pendleton Branch Experiment Station.
[b]From T. T. Chao, M. E. Harward, and S. C. Fang, Oregon Agricultural Experiment Station, Project 310, unpublished data.
[c]Personal communication from Dr. E. G. Knox, Associate Professor of Soils.
[d]Names may be changed because of redefinition of the series.

amount of water sufficient to maintain microbial potentialities that could actively develop upon subsequent incubation. The treatments, prepared in duplicate, included the herbicides at 0, 5 and 100 ppm, the 5 ppm rate being comparable to field applications. Simazin and diuron were applied and mixed with the soil as water suspensions: EPTC and 2,3,6–TBA as emulsions. The bottles were incubated in a randomized block design at 28 ± 1° C. and connected to a modified Potter and Snyder (11) respiration apparatus designed by Bollen (4). Moisture was maintained at 50 per cent of the moisture capacity. The carbon dioxide evolved was absorbed in tubes containing N/1 NaOH. The tubes were replaced at the end of 42, and 84 hours, and 7, 14, 28 and 56 days and absorbed carbon dioxide was determined by differential titration with N/1 and N/12 H_2SO_4. The end points used were those recommended by Cooper (5); pH 8.35 for neutralization of excess NaOH and conversion of carbonate to bicarbonate, and pH 5 to 4.6 for bicarbonate titration, the particular end point varying according to the amount titrated.

RESULTS AND DISCUSSION

Results shown for carbon dioxide evolution are the means of two replications which had a standard deviation of 2.7 to 4.8 per cent of the mean values. The results are plotted on a cumulative basis for several intervals in Figures 1, 2, and 3. The soils are shown in order of their increasing clay content.

Carbon dioxide production was always greater in the untreated soils. More extensive evolution from the Knappa and Astoria soils may be attributed to their higher organic matter contents. The order of respiration by the different soils is approximately in the order of their organic matter content, except for the Deschutes sandy loam. This soil, while lowest in organic matter, is coarsest in texture and thus subject to most rapid aeration, which probably accounts for its high carbon dioxide evolution. Texture and aggregation, reflected to some degree by moisture capacity, and C:N ratio as well as amount of organic matter, all influence rate of decomposition under given incubation conditions. The pattern of carbon dioxide evolution from the untreated soil is therefore a primary characteristic and is here used as a reference for comparing the effects of the herbicides on the general soil microflora.

Although there were obvious differences between the soils in their response, each herbicide depressed carbon dioxide evolution, the per cent decrease generally being greatest at 28 days. In only two of the 72 treatments, which included nine soils, four herbicides and two rates, was the depression significantly greater at 56 days. By this time in all other cases the depressive effect declined, save for a few instances in which it remained relatively constant. The general decrease in effect after 28 days could indicate acquirement of microbial tolerance for the herbicides, their decomposition, or their inactivation by sorption on organic matter or clay.

Figure 1. Carbon dioxide evolution from light textured soils treated with herbicides.

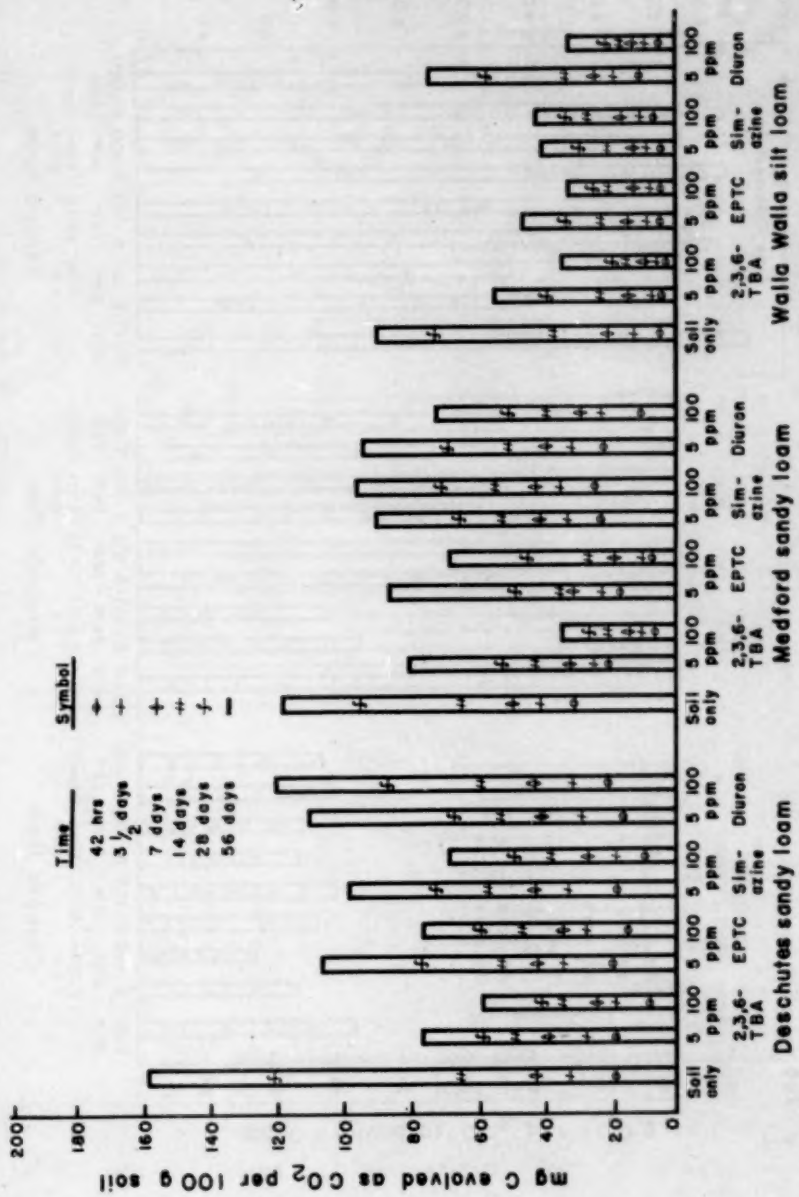


Figure 2. Carbon dioxide evolution from medium textured soils treated with herbicides.

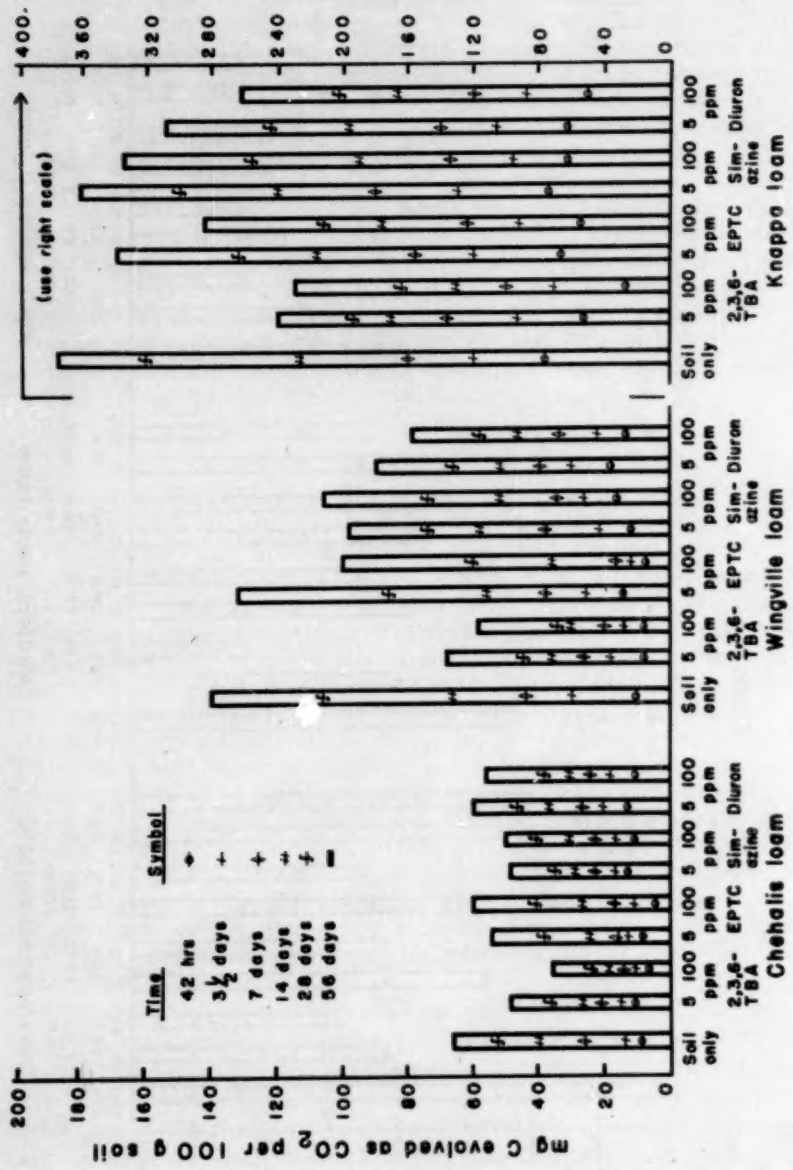
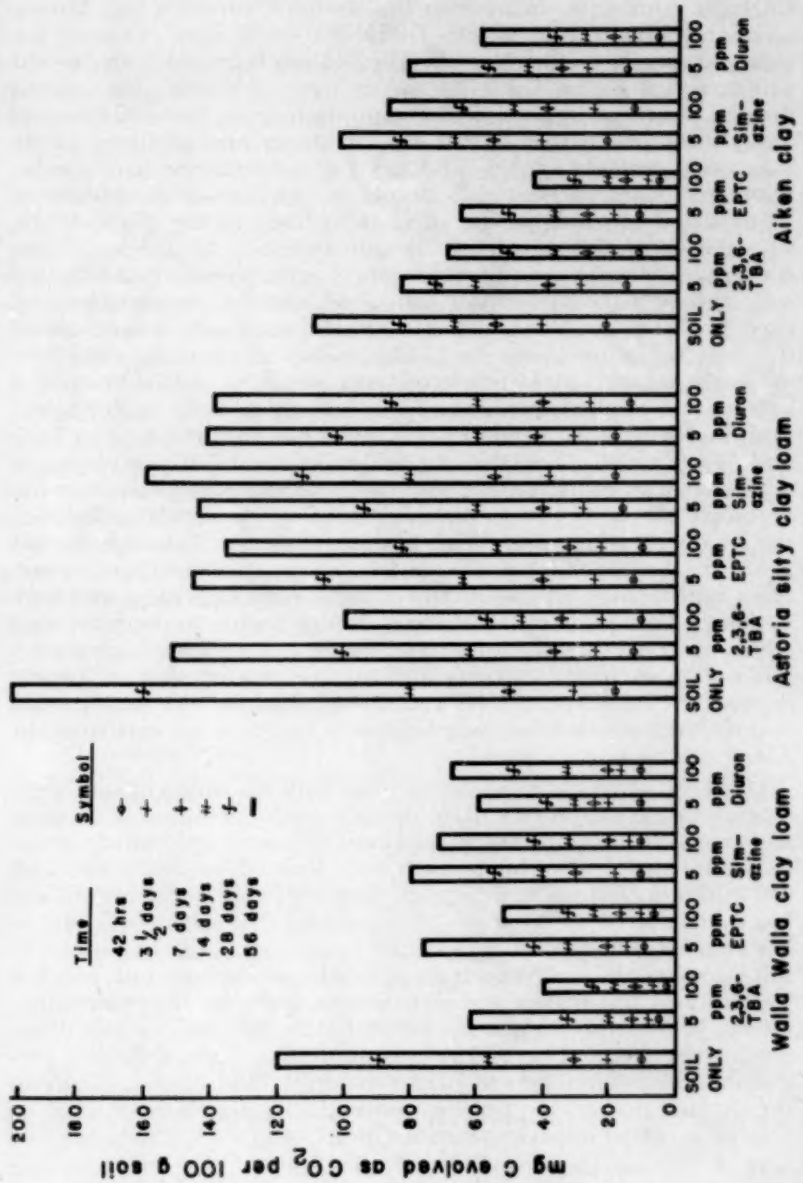


Figure 3. Carbon dioxide evolution from heavy textured soils treated with herbicides.



The depression of carbon dioxide evolution was greater with applications of 100 ppm than with 5 ppm except with EPTC on Chehalis loam, with simazine on the Medford, Chehalis and Astoria soils, and with diuron on the Deschutes sandy loam. Reasons for these exceptions are not known. They do not correlate with the soil properties listed in Table 1, and it seems unlikely that carbon dioxide produced by possible decomposition of the herbicides would appreciably lessen the depression. Deschutes and Medford sandy loam soils reacted to 2,3,6–TBA, EPTC and simazine in a similar pattern, showing marked reduction in carbon dioxide production at 28 days and lessening of the effect at 56 days. In the Walla Walla soils the depression in carbon dioxide evolution by the herbicides was generally more pronounced in the virgin than in the cultivated soil, although the virgin soil contained more organic matter and clay. The Chehalis, Wingville, and Knappa loam soils showed widely different responses to the herbicides, indicating that the same textural classification does not necessarily result in similar microbial effects of the applied chemicals. These differences could be due to soil type, including organic matter content, as has been reported by Ogle and Warren (10). However, the wide differences in percentage of organic matter in these three soils did not consistently influence the herbicide effects on carbon dioxide evolution. As shown in Table 1, the Knappa soil has a very high lime requirement, although the pH is 6.2; the Astoria soil, pH 5.3, has an even greater lime requirement. High acidity, high organic matter content, wide C:N ratio, and high exchange capacity of these two soils do not appear to correlate with effects observed on respiration. The Aiken soil, which is high in clay but not in exchange capacity and organic matter, showed greater depressive effects from EPTC and diuron than did the Knappa and Astoria soils, which have more organic matter and less clay than the Aiken soil.

Diuron showed different interactions with the different soil types. At each rate it depressed carbon dioxide production most at 14 days, and it was least depressive in Chehalis silt loam soil, which is low in organic matter. Deschutes sandy loam showed less inhibition with 100 ppm diuron than with 5 ppm. Although each herbicide showed low inhibition in the Knappa soil, suggesting that soil organic matter has an ameliorating influence on the toxicity of these compounds to soil microbes, the lesser effects on Deschutes sandy loam soil, which is lowest in organic matter and clay content, indicates that some other factors besides the organic matter and clay are important in determining the effects of herbicides on inhibition of carbon dioxide production. Such differences as parent material, kind of clay, nature of the organic matter, level of nutrients and nature of the microflora may be involved in various combinations.

In a few instances, notably by simazine in Knappa loam and Aiken clay soils at 7 and 14 days, carbon dioxide evolution was temporarily increased 12 to 14 per cent by herbicide treatment at the lower rate. These examples accord with the Hueppe principle

pertaining to germicides: sub-inhibitory concentrations of toxic agents often stimulate microorganisms.

SUMMARY AND CONCLUSION

The carbon dioxide evolution data disclose no consistent pattern for the influence of organic matter and clay on the effects of the herbicides on soil respiration. The data do emphasize that different results are obtained with different soil types and that in some cases organic matter and clay may be important. Because herbicides applied to the soil may be decomposed chemically, decomposed by microbes, absorbed by soil colloids, or lost by vaporization, various physical, chemical and microbial properties of the soil may be involved as well as organic matter and clay. Further investigations with different soils should include a complete physical, chemical and microbial characterization of the soils used.

The herbicides in most cases decreased the rate of carbon dioxide evolution for at least 28 days. The different soils respond differently; however, the effect of the compounds generally declined gradually and the inhibition of respiration decreased considerably by 56 days. It appears possible, therefore, that pre-emergence applications would have minimum influence on subsequent microbial activities affecting plant growth.

Higher rates of the herbicides did not show inhibitions in proportion to the concentrations applied to different soils.

Soil type and environmental factors should be explored in more detail to determine their influence on the reciprocal effects of herbicides and microorganisms in the soil.

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Persistence and Movement of CDAA and CDEC in Soil and the Tolerance of Corn Seedlings to These Herbicides[1]

R. L. Gantz[2] and F. W. Slife[3]

One of the major characteristics limiting the usefulness of pre-emergence herbicide applications concerns the persistence of chemical activity in the soil. In many instances, the herbicides break down too quickly to obtain satisfactory weed control. On the other hand, there is the possible hazard that a chemical may be too persistent and thus endanger the growth of succeeding crops. Another closely related factor is susceptibility to leaching. It is especially important when chemicals are used that are toxic to the crop plants as well as the weeds.

In 1954, two new compounds were introduced for use as pre-emergence herbicides in crops (7, 8). These herbicides were 2–chloro–N,N–diallylacetamide (CDAA) and 2–chloroallyl diethyldithiocarbamate (CDEC). Preliminary data indicated that both of these compounds were more specific for annual grass weeds than for broadleaf weeds. The object of this study was to learn more about the persistence and movement of CDAA and CDEC when applied to the soil. Since corn would be a major crop on which CDAA and CDEC might be used, laboratory tests were conducted to learn the actual tolerance of corn seedlings to these pre-emergence herbicides in soil.

Review of Literature

A majority of the reported work with herbicidal decomposition and leaching has involved the hormone herbicides.

Investigations have indicated that microbial detoxification controls herbicidal persistence in the soil and that temperature, moisture, and organic matter content favoring greater microbial activity likewise accelerate the decomposition of herbicides (5, 13, 15). Microorganisms capable of breaking down 2,4–D have been isolated by Audus and Symonds (3) and Jensen Peterson (11).

In humid agricultural regions, leaching is one of the major factors influencing the success of pre-emergence applications. Excessive rainfall can decrease herbicidal effectiveness but relatively large amounts are necessary to completely eliminate herbicidal toxicity from the surface one or two inches of soil (9, 14, 17). The chances of losing pre-emergence weed control through leaching appear to be

[1]From a thesis submitted by R. L. Gantz in partial fulfillment of the requirements for the degree of Master of Science in Agronomy, University of Illinois, 1956.

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much greater in soil low in clay and/or organic matter content (6, 10, 12, 20). Fixation of herbicides helps reduce leaching losses in soils having high exchange capacities (2, 4). Chemical formulation has also been found to be an important factor according to Aldrich (1) and Warren (20), who found the esters of 2,4–D to be more resistant to leaching than the amine formulations.

PERSISTENCE OF CDAA AND CDEC IN SOIL

The cited literature indicates that the two most obvious factors affecting herbicidal breakdown under pre-emergence conditions usually are temperature and moisture. Even though persistence actually may be dependent upon biological activity or chemical decomposition, the indirect effects of temperature and moisture are of paramount importance. This paper describes experiments studying the influence of different temperature and moisture conditions upon the persistence of CDAA and CDEC in soil.

Materials and methods.

A Muscatine silt loam soil was subjected to three treatments: CDAA, CDEC, and no chemical treatment (untreated checks). Each treatment was replicated four times and exposed to temperatures of 40°, 60°, 80°, and 100° F. For each temperature, the soil was incubated in a moist (approximately field capacity) and an air dry condition. The material was sampled and assayed for toxicity to germinating cucumbers at 0, 2, 4, 6, and 8 weeks in a manner similar to that described by Ready and Grant (18).

Fifty-gram samples of air dry soil were placed in 480 six-ounce round tin boxes and sprayed, where appropriate, with CDAA and CDEC at a rate equivalent to 8 lb/A. After the soil dried somewhat, it was stirred and mixed thoroughly in each can. Water was then added to the samples designated for the moist soil condition. All the material was placed in the appropriate temperature chambers except that withheld for the initial sampling. All the thermostatically controlled chambers had forced-air circulation except the one set at 40° F.

For each sampling, four replications of the three treatments under both moist and dry conditions were randomly withdrawn from each of the temperature chambers. The soil in each of the moist samples which had been watered tri-weekly during incubation, was allowed to dry and then stirred and mixed. All of the soil samples were transferred to nine-centimeter Petri dishes and planted with 15 cucumber (*Cucumis sativus*, Early Fortune variety) seeds per dish. After adding 22.5 cc of distilled water, each dish was covered and placed on a laboratory table where the temperature varied from about 25° to 30° C. The covers were left on the dishes for approximately 24 hours to maintain highly humid conditions. Distilled water was then added periodically during the remainder of the growing period of 96 hours. At the end of this period, the primary roots were washed free of soil and measured in millimeters.

Results and discussion.

These results (Table 1) showed that both herbicides remained active two to four weeks longer in dry soil than in moist soil at the two higher temperatures. In moist soil, CDAA toxicity had disappeared in four weeks and both herbicides were inactivated by the end of six weeks of storage at 100° and 80° F. These results agree quite well with more recently completed work reported by Otten, et al. (16) and Sheets (19), except that Otten, et al. observed faster decomposition in moist soil.

Table 1. The persistence of CDAA and CDEC in a Muscatine silt loam soil when exposed to different temperature and moisture conditions. (Each datum represents an average of four replications of 15 seeds each.)

Incubation time weeks	Cucumber root growth as per cent of control, following incubation at (°F.)							
	CDAA[a]				CDEC[a]			
	100°	80°	60°	40°	100°	80°	60°	40°
	Moist[b]							
0	26	27	28	25	34	28	34	29
2	42	20	23	22	36	28	27	24
4	102	79	25	21	70	71	26	25
6	106	97	21	23	97	96	26	28
8	100	98	27	28	96	102	48	31
	Air dry[c]							
0	28	29	26	21	38	31	32	27
2	56	54	25	20	64	69	32	24
4	65	58	29	20	74	76	33	25
6	63	76	25	24	77	92	26	29
8	82	75	29	36	95	96	40	43

[a]The herbicides were applied at the rate of eight pounds per acre.
[b]During incubation, an attempt was made to maintain uniform moisture conditions regardless of temperature. Distilled water was added three times per week to maintain a condition approximating field capacity.
[c]The soil was air dry during incubation.

The inverse relationship between persistence and temperature, reported by many investigators, was also evident in this experiment. Herbicidal toxicity diminished most rapidly at 100° and 80° F. There was very little apparent breakdown of either CDAA or CDEC at the two lower temperatures, but a definite break in persistence occurred between 60° and 80° F, especially for CDAA. These pre-emergence herbicides might be of more value on early spring planted crops since their residues persist longer at lower temperatures.

The results of this experiment indicate that CDAA and CDEC are probably inactivated biologically. Otten, et al. (16) have also indicated that soil microorganisms are involved. Audus and Symonds (3) found that the biological detoxification of growth regulator herbicides in soil is characterized by a lag phase of varying duration and then a rapid phase of complete inactivation. The results in Table 1 tend to agree with this, particularly in the moist soil treatments at 80° and 100° F.

From the practical standpoint, it seems reasonable to conclude that under the climate common to the Corn Belt, the application of these herbicides should cause no lengthy soil residue problems.

MOVEMENT OF CDAA AND CDEC IN SOILS

Laboratory studies were designed to investigate the relative movement of CDAA and CDEC in Muscatine silt loam and Oquawka sand under uniform artificial rainfall conditions. Some of the physical and chemical properties of surface samples of these Illinois soils appear in Table 2.

Table 2. The approximate chemical and physical characteristics of the surface samples of the soils used for the movement studies.

Soil type	Sand pct	Silt pct	Clay pct	Volume weight gm/cc	Organic matter pct	Base exchange capacity me/100 gm	pH
Muscatine silt loam.	1.9	70.1	28.0	1.2	5.6	25.7	5.3
Oquawka sand.....	99.0	<1.0	<1.0	1.6	0.1	3.3	6.2

Separate experiments were run for each soil type, but the methods were the same for both experiments.

Materials and methods.

Soil columns were prepared by placing a definite weight of soil into "Visking" cellulose casings. The amount of soil in each column was dependent upon the volume weight. The settled columns of soil were six inches high and three inches in diameter.

Leaching was accomplished by subjecting each of the soil columns to four surface inches (448 cc.) of distilled water, metered drop by drop, from 50-ml. burettes. The rate of application was adjusted according to the infiltration rate of the soil. The columns were moved or rotated frequently in order to give an even distribution of water on the soil surface. The treatments are explained in footnotes to Table 3. The leachates were not tested for CDAA or CDEC because of fungal contamination.

Fifteen cucumber seedlings were transplanted into each of the stirred soil layers sectioned from the leached columns. Mean root elongation after 72 hours at a laboratory temperature of approximately 25° C., was the criterion of observation. A randomized block design was used for both experiments.

Results and discussion.

For comparative purposes, percentage transformations of the results, appearing in Table 3 and the resulting "growth index" values are described and presented in Table 4. This transformation made possible the direct comparison of the movement of CDAA and CDEC in both soil types.

Table 4 shows that CDAA was leached much more than CDEC in both soils, which is in agreement with results published by Otten, et al. (16). In the silt loam, CDAA toxicity in the surface inch was not reduced by leaching even when equally toxic residues were found in the lower soil layers. The retention of CDAA in the surface layer is believed to be due to fixation in the soil. This belief is based

Table 3. The primary root elongation of cucumber seedlings after 72 hours in the first four upper one-inch layers of leached soil columns subjected to various treatments.

Leached layers of soil column	Mean root elongation (mm) of four replications with 15 seedlings per replication				
	Untreated checks[a]	Treated controls[b]		Leached treatments[c]	
		CDAA	CDEC	CDAA	CDEC
	Muscatine silt loam				
1st inch	67.7	19.2	25.8	21.4	30.8
2nd inch	71.7	18.8	32.6	17.7	63.4
3rd inch	69.7	19.1	27.3	22.0	70.3
4th inch	75.6	18.0	29.6	41.1	71.5
General mean[d]	71.2	18.8	28.8	—	—
	Oquawka sand				
1st inch	82.6	19.1	18.2	67.0	21.1
2nd inch	80.3	19.5	18.4	70.6	32.0
3rd inch	78.3	19.0	19.7	70.2	69.0
4th inch	75.0	20.4	20.7	71.3	66.4
General mean[d]	—	19.5	19.2	—	—

[a]Columns were leached and sectioned but not subjected to herbicidal treatment.
[b]Columns were leached with distilled water, sectioned, and the individual layers were then treated with CDAA or CDEC at the rate of four pounds per acre. These treatments were used for comparison with the leached treatments.
[c]Surface of the soil column was treated with CDAA or CDEC at the rate of four pounds per acre. The treated columns were then leached and sectioned.
[d]General analysis of variance F tests were run on untreated checks and treated controls. Non-significance permitted the use of the general mean as a valid representative value for the whole column. Significance indicated the general mean was not representative. The general mean appears only when the general F test indicated no significance at the five per cent level.

Table 4. The toxicity of CDAA and CDEC in two soils after leaching from the surface as indicated by the primary root elongation of cucumber seedlings in 72 hours. (The data in Table 3 transformed to growth index values.)

Soil type	Growth index[a]							
	CDAA One-inch soil layers				CDEC One-inch soil layers			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Muscatine silt loam	5.0	−2.1	6.1	42.6	4.7	81.6	97.9	100.9
Oquawka sand	75.3	84.0	86.2	93.3	3.0	20.9	83.4	84.6

[a]Growth index $= \frac{\text{Leached treatment} - \text{Treated control}}{\text{Untreated check} - \text{Treated Control}} \times 100$

General mean values from Table 3 were used where general analysis of variance F tests indicated no significance existed.
Example—the growth index for the Muscatine, CDAA, 1st inch, is as follows from Table 3:

$$\text{Growth index} = (21.4 - 18.8)/(71.2 - 18.8) \times 100 = 5.0.$$

The growth index represents the amount that root elongation in the leached treatment exceeds that in the treated control, expressed as a percentage of the difference between the root elongation in the untreated check and the treated control.

on a report by Hannah (8) that the chloroacetamides are adsorbed by the organic matter and/or clay in the soil, but not in a manner which inhibits their herbicidal activity. Even though CDAA may be quite soluble, adsorption would seem to prevent leaching from causing a loss of herbicidal effectiveness in medium and heavy textured soils.

It was apparent from Table 4 that CDAA toxicity was largely removed from all four sample layers of Oquawka sand. In both soils, CDEC was just as toxic in the first inch after leaching as it was before leaching. CDEC toxicity was not evident beyond the second inch in the silt loam. The sand showed some CDEC toxicity in the third and fourth inches. In general, leaching caused greater movement of both herbicides in Oquawka sand than in Muscatine silt loam.

Table 3 indicates that CDAA was more toxic than CDEC in the silt loam, but both herbicides were equally toxic in the sandy soil. By comparison, Sheets (19) found CDAA always to be more toxic than CDEC but his sandiest soil had 16% clay as compared to less than 1% clay in the Oquawka sand used in this study. Table 4 shows that leaching removed most of the CDAA toxicity from Oquawka sand, but the herbicidal effectiveness of CDEC was not diminished by leaching. This indicated that CDEC would be a more suitable herbicide to use on sandy soils.

TOLERANCE OF CORN SEEDLINGS TO CDAA AND CDEC IN SOIL

Since corn is one of the major crops on which CDAA and CDEC could be used, the actual tolerance of germinating corn to these chemicals was tested.

Materials and methods.

Fifty-gram samples of a Muscatine silt loam were treated at various rates of the herbicide under test. The air-dry soil samples were contained in six-ounce tin boxes. Six replications of 15 rates of CDAA and CDEC were prepared as 10-ml. solutions and sprayed uniformly on the soil surface. The rates, varying from 0 to 32 pounds per acre, were applied in logarithmic increments.

The soil samples were allowed to dry somewhat, stirred, and then transferred to Petri dishes. Ten corn (hybrid U. S. 13) seedlings having roots approximately ½ cm long, were planted in each of the samples. Water was added and the dishes were covered for 10 or 12 hours to ensure humid conditions. The completely randomized material, situated in controlled room temperatures of approximately 25° C., was watered periodically during the remainder of the 72-hour growing period. After this time, the average primary root elongation of each replicate of each treatment was determined. For comparative purposes, cucumber seedlings having one-cm root lengths, were subjected to the same treatments except that 15 seedlings were grown in each sample.

Results and discussion.

Figure 1 shows that CDAA is more toxic to cucumbers than CDEC. Both herbicides seemed to have about the same toxicity for corn except that the 32-pound rate of CDAA was somewhat more toxic than the same rate of CDEC. Statistical analyses indicated that the root elongation of corn did not differ significantly from the untreated checks until a rate of eight pounds per acre was applied.

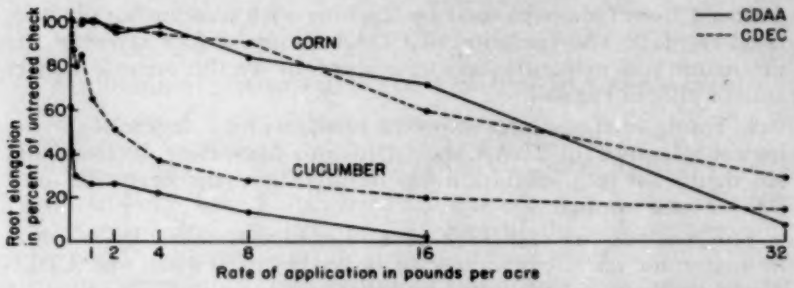

Figure 1. The primary root elongation of cucumber and corn seedlings after 72 hours in Muscatine soil samples treated with CDAA and CDEC at various rates.

Kermicle[5] found germinating corn to be fairly tolerant to CDAA and highly tolerant to CDEC in a Sable silty clay loam soil. Corn was very sensitive to 2,4–D under the same experimental conditions. It should be kept in mind that the tolerance which corn showed for these herbicides in these experiments is physiological since the herbicides were mixed into the soil. This study indicates that corn has considerable tolerance to CDAA and CDEC.

SUMMARY AND CONCLUSIONS

Laboratory experiments were conducted to study the persistence and movement of CDAA and CDEC in soil under various conditions. The tolerance of corn seedlings to these herbicides in soil was also investigated and compared with the reaction of cucumber seedlings under the same conditions.

1. The toxicity from 8 lb/A of CDAA and CDEC disappeared more rapidly in a Muscatine soil at 100° and 80° F. than at 60° and 40° F. In moist soil, CDAA toxicity had disappeared in four weeks, and both herbicides were inactivated by the end of six weeks of storage at 100° and 80° F. In general, both CDAA and CDEC remained active longer in dry soil than in moist soil at 100° and 80° F. There was very little apparent breakdown of CDAA and CDEC at 40° and 60° F. during eight weeks of incubation regardless of the soil moisture condition. The application of these pre-emergence herbicides should cause no soil residue hazards to succeeding crops in the cornbelt area.

2. In leaching studies, CDAA was more toxic than CDEC in Muscatine silt loam, but both were equally toxic in Oquawka sand. Leaching caused greater movement of both herbicides in the sandy soil than in the silt loam. In both soils, CDEC was leached much less than CDAA and was just as toxic in the surface inch after leaching as it was before leaching. CDAA toxicity in the surface inch of the silt loam was not reduced by leaching even when equally toxic residues were found in the lower soil layers. CDAA was largely

[5]Kermicle, P. D. A study of the herbicidal properties of several acetamides and dithiocarbamates applied as pre-emergence sprays. Unpublished Master's thesis. University of Illinois. 1955.

removed from Oquawka sand by leaching with four inches of simulated rainfall. The retention of CDAA in the surface layers of the silt loams was evidently due to adsorption by the organic matter and/or clay in the soil.

3. Young corn seedlings showed a relatively high degree of physiological tolerance for CDAA and CDEC in a Muscatine silt loam soil. No significant root inhibition was induced by either herbicide until 8 lb/A were applied.

The root toxicity and leaching studies suggest that CDAA would be better for use on moderate or heavy textured soils, and CDEC would be better on the sandy or lighter soils.

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Simazine for Annual Weed Control in Cranberries

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INTRODUCTION

ANNUAL weeds have always been a problem to the cranberry grower, but certain changes taking place in the bog environment have caused an increase in the population of annual weeds in some areas in recent years. The decline of soil acidity as a result of the long term use of alkaline water for frost flooding, coupled with the well drained bog culture recommended for Wisconsin growers, have produced an environment to which certain annual weeds are adapted. With some species, particularly common ragweed *(Ambrosia artemisiifolia),* the extensive use of petroleum products as herbicides has encouraged the invasion of annual weeds following the suppression of oil sensitive perennials.

An effective pre-emergence herbicide for use in cranberry bogs would be a material with a low solubility in water, a long residual action, and herbicidal activity on a wide range of weed species. Simazine (2–chloro–4,6–bis (ethylamino)–*s*–triazine), an herbicide that has been widely accepted for use in corn, embodied all of these properties (2, 3). A preliminary study (4) showed that cranberry plants were tolerant of this material at rates of 2 and 4 lb/A. A report from Washington (1) indicated tolerance of the vines to applications at rates as high as 12 lb/A.

The early reports of effectiveness and known properties of simazine encouraged evaluation of this material to provide information about the tolerance of cranberries to the herbicide on soils of different textures and at different rates of application, and to determine its effectiveness against several annual weeds of cranberry bogs.

MATERIALS AND METHODS

Granular simazine was diluted with dry sand and applied to the plots with a small fertilizer spreader. Granular material was used in order that all of the applied herbicide would sift through the cranberry vines to the bog floor, the location of weed seed germination. All applications were made in mid-April to cranberry sections from which the winter flood had recently been removed.

All vines were fully dormant at the time of treatment. Common ragweed; tearthumb smartweed, *Polygonum sagittatum;* and beggarticks, *Bidens connata* seedlings, in the cotyledonary stage, were found in some of the plots on the dates of the herbicide applications.

The plots from which yields were obtained were arranged in randomized blocks. The experiments in Bogs A, B, and C were arranged with four replicates while that in Bog D had six replicates. Observa-

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tional plots were established at five other locations in the 1958 season.

The plots in Bogs A, B, and C were located in plantings of Searles Jumbo vines. The plots in Bog D were located in a section of the McFarlin variety. The soil at all these locations was a peat overlain with an accumulation of several inches of sand. No new sand had been applied in the last five years. The unreplicated, observational plots were located on sections with soil conditions ranging from freshly sanded plantings to virgin peat that had never received any sand application.

Yields were obtained by hand-raking and weighing all berries from each plot. Berries were weighed immediately after the harvesting was completed. Fruit size determinations were made by counting the number of berries that were required to fill a standard measuring cup (½ pint). Three random samples per plot were counted. A large cup count indicates small berries and a small cup count shows large berries.

RESULTS

Yield and berry size.

The average yield and cup count data for four locations are summarized in Table 1. Those plots that received the 1 lb/A rate of

Table 1. Total yield and berry size of cranberries harvested from simazine treated plots.

Simazine application lb/A	1958				1959			
	Bog A		Bog B		Bog C		Bog D	
	Yield bbl/A	Cup count no.	Yield bbl/A	Cup count no.	Yield bbl/A	Cup count no.	Yield bbl/A	Cup count no.
0	189	83	243	94	218	89	202	99
1	—	—	—	—	247	89	226	96
2	177	85	210	95	220	90	210	104
4	159	80	200	98	204	87	170	104
8	104	90	—	—	—	—	—	—
L.S.D 5%	n.s.	n.s.	n.s.	4.0	n.s.	n.s.	23.0	n.s.

simazine application produced 13.3% and 11.9% more cranberries than the comparable check plots in Bog C and Bog D respectively. The increased yield in Bog D was statistically significant at the 5% level of probability. The increase in yield in Bog C was very close to the 5% level of probability in the statistical analysis. The increase in yield was associated with the weed stand reduction shown in Table 2.

Plots treated with 2 lb/A of simazine in 1958 showed a slight reduction in yield when compared with the untreated controls, Bogs A and B. This rate of treatment did not cause a yield reduction in 1959, Bogs C and D. The 4 lb/A treatments resulted in sizeable yield reductions at all four locations.

Table 2. The average number of weeds per plot (100 sq. ft.) for three bog locations.

Simazine lb/A	Bog B			Bog C	Bog D
	Ragweed	Tearthumb	Beggarticks	Ragweed	Beggarticks
0	60	21	4	584	350
1	—	—	—	74	53
2	5	1	1	9	4
4	1	1	0	1	0

In Bog A the 8 lb/A treatment caused a crop reduction of 45%. The yield reductions found in the 4 and 8 lb/A plots were not significant in the statistical analyses due to the large variations within treatments.

Berry size, as shown by the cup count data, was not altered significantly by herbicide treatment in Bogs A, C, or D. A significant increase in berry size in the 4 lb/A plots of Bog B was shown by the statistical analysis. This increase was small and was not considered to be of practical significance.

Close visual examination of the berries at the time of harvest revealed no differences in color or quality associated with the herbicide treatments.

Injury to the vine foliage was noticeable in the 8 lb/A plots located in Bog A. No injury was apparent on any of the other plots for which yields are shown in Table 1.

Vine injury was common in the observational plots established in the 1958 season. A definite relation between the degree of injury and the soil type was noted. On young bogs, in which the vines were planted through four inches of sand, or on those mature bogs on which one inch of fine sand had been applied the previous winter, the injury developed earlier, and was more severe for a given rate of treatment, than was true on bogs planted in peat soil. Applications of simazine at 4 lb/A on freshly sanded areas resulted in moderate to severe foliage injury. Four pounds per acre of simazine on bog sections not freshly sanded resulted in none to very slight injury. Eight pounds per acre on bog sections not freshly sanded resulted in slight to moderate injury. In no instance was there any foliage injury in plots where 1 lb/A or 2 lb/A of simazine was used regardless of the soil texture.

Vine injury started to develop in late June as the vines were in their period of rapid growth. The first symptom of injury was a marginal browning of young leaves at the 4th or 5th node below the apex. The necrotic area slowly expanded to include the whole leaf which then fell from the plant. Additional young leaves became injured as the season progressed until the uprights on severely injured plants were completely denuded of new foliage. Old foliage from the previous years' growth developed no necrotic areas and was not shed from the plant, although in severely injured plots this foliage developed a dull gray-green color that contrasted sharply with the normal bright green leaves of uninjured plants. The devel-

opment of new uprights and the extension of runner growth was severely restricted in amount in plots where defoliation of new upright growth occurred. This injury was noted as a lack of growth rather than the development of any characteristic morphological aberrations.

Weed control obtained by simazine treatment.

Due to the sparse stand of weeds in both the treated and untreated plots in Bog A, no attempt was made to measure the degree of weed control obtained. In Bog B, a good stand of annual weeds developed in the control plots and in the field surrounding the plot area. Weeds in this area were common ragweed, tearthumbs and beggarticks. In Bog C there was a heavy population of common ragweed in the plot area and in Bog D a heavy stand of beggarticks. Weed counts were made for plots in Bogs B, C, and D. The data are summarized in Table 2.

A practical degree of weed control was attained in all trials at all rates of simazine applications. A better distribution of herbicide in the 1 lb/A plots would likely have produced greater weed control. Small amounts of granular material are not well distributed by conventional equipment. The distribution pattern improves as the quantity of applied material increases. The strip pattern of weed growth in the 1 lb/A plots indicated that this indeed was the explanation for the failure to attain more nearly perfect weed control in these plots.

The non-replicated, observational plots at several other bog locations demonstrated that applications of 2 lb/A or more of simazine would control beggarticks, *Bidens coronata;* panic grass, *Panicum sp.;* and smartweed, *Polygonum pennsylvanicum.* In no instance were any perennial weeds controlled by the rates of simazine used.

DISCUSSION

A material with the properties possessed by simazine should find wide acceptance in Wisconsin cranberry culture. Applications may be made in early spring after the removal of the winter flood and before the spring frost flooding period commences. During this period, approximately three weeks, the bog sections are free of flooding water that may interfere with mechanical operations. Also the vines have not commenced growth and, therefore, are not greatly harmed by the wheels of mechanical equipment that may be used to apply the herbicide. Once the vines have commenced growth they are subject to mechanical injury from any equipment that may be used on the bog. The frequent frost floods that are applied during May and early June not only interfere with mechanical operations directly but also disrupt scheduling of bog operations because they are unpredictable in time and duration.

A standard practice in Wisconsin is the application of a one-inch layer of sand every third year to established cranberry fields. This sand layer serves the functions of 1) reducing the frost danger by

increasing the rate of soil heat conduction on frosty nights 2) reducing the population of certain weeds 3) covering up the cranberry runners and stimulating them to root at frequent intervals, and 4) weighting down the vines which facilitates the use of mechanical equipment for harvesting. The relationship between soil texture and the incidence of simazine injury noted in this study suggests that rates of application of this herbicide must be carefully considered with regard to the sanding operation. Bog sections which have been sanded the winter prior to herbicide treatment should receive no more than 1 lb/A of simazine while bog sections on peat soil or on old sand may be treated with 2 lb/A. Two years results have shown that practical weed control was obtained with 2 lb/A of simazine on peat soil.

It is common knowledge that in order for simazine to be effective the soil moisture must be at a satisfactory level for weed seed germination. The soil conditions under which cranberries are grown would seem to provide excellent moisture conditions for the best efficiency of this material. The evidence presented here supports this observation.

SUMMARY

Simazine was tested for two years as an herbicide for the control of annual weeds in cranberry bogs. A granular formulation of the herbicide was used for all tests.

Simazine at 8 lb/A resulted in foliage injury in plots at six different bogs. A crop reduction of approximately 45% due to this treatment occurred at one bog. Four pounds per acre resulted in foliage injury of some severity at five locations and no injury at four locations. No injury resulted from applications of 1 lb/A or 2 lb/A. The degree of injury was correlated with soil texture. The most severe injury occurred on bogs planted in sand or those that had been recently sanded as a cultural practice.

Control of ragweed, beggarticks (2 species), annual smartweed (2 species), and panic grass, was excellent at all rates of herbicide treatment.

Yield increases were found when 1 lb/A of simazine was used on very weedy sections. A rate of 2 lb/A resulted in little effect on berry yield but 4 lb/A caused some reductions in yield.

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The Influence of Concentration of Fumigant and Time of Exposure on the Killing of Dormant Imbibed Seeds[1]

STANLEY J. PIECZARKA[2] and G. F. WARREN[3]

THE literature does not reveal any direct information concerning the time of exposure or concentration required of a soil fumigant to kill weed seeds. For specific soils and conditions the appropriate rate of application may be known but this does not represent an actual toxic concentration. This is due to the fact that the toxicity of the fumigant may be decreased due to adsorption of the fumigant by the soil or solution in the soil water. This investigation was carried out to determine what concentration of fumigant is needed for a specific time to produce a given percent control of dormant imbibed seeds.

MATERIALS AND METHODS

The technique used was a modification of that described by Pieczarka and Warren (4). They found that they could successfully keep seeds imbibed with moisture and yet prevent them from germinating by holding the seeds at temperatures below that required for germination. When removed to a suitable environment, the seeds germinated as rapidly and completely as non-treated seeds. Because of this restriction the entire experiment was carried out at 48° F.

Fifty seeds each of tomato *(Lycopersicon esculentum)*, and pigweed *(Amaranthus retroflexus)* were counted out on filter paper in 9 cm. Petri dishes. These were moistened and held at 48° F. for one week. Five Petri dishes each of tomato and pigweed seeds with covers removed were placed inside specimen bottles that had a capacity of 11.36 liters. An empty Petri dish was placed in the container and the fumigant was introduced into this dish. A polyethylene sheet was placed over the mouth of the container and the cover screwed tight. There were two replications of each concentration, time, and fumigant used.

The relative range of concentrations and times needed was determined for the fumigants by preliminary tests. The times and concentrations finally used are shown in the tables of results. After the fumigation time had expired the containers were opened and ventilated with a fan for 1½ hours to remove the fumigant. The Petri dishes with covers replaced were moved to a room where the temperature range was 75–80° F. Germination counts were made and the percentage kill was calculated from the germination of the checks, which averaged 90 percent for tomatoes and 45 percent for pigweed.

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RESULTS

In Tables 1 to 4 data are presented which show the influence of time and concentration of four fumigants on the percent kill of dormant imbibed tomato and pigweed seeds. It is noted that for a particular time period as the concentration of fumigant decreased the percent kill also decreased. On the other hand, for any one concentration of fumigant used, with increasing time of exposure, the percent kill of tomato and pigweed increased. The only exception is allyl alcohol (Table 4) where the activity was so high, within the range of times and concentrations used, that this relationship could not be shown.

Table 1. Influence of time and concentration of 1,3-dichloropropene vapors on percent kill of tomato and pigweed seeds.

Time in hours	Concentration of fumigant in mg per liter of air								
	220	176	132	88	44	22	10.6	5.3	2.6
					Tomato				
0.5	81	74	74	69	52	37	38	36	32
1	93	88	91	84	78	60	54	50	46
1.5	100	100	98	95	95	88	49	47	43
2	100	100	99	98	96	82	83	67	76
3	100	100	100	100	99	87	84	72	69
4	100	100	100	100	100	94	99	84	75
					Pigweed				
0.5	86	91	79	70	62	43	52	46	37
1	100	96	99	98	90	60	55	48	46
1.5	100	100	100	100	99	100	68	65	61
2	100	100	100	100	100	94	96	67	63
3	100	100	100	100	100	96	94	85	76
4	100	100	100	100	100	100	96	88	81

Table 2. Influence of time and concentration of SMDC vapors on percent kill of tomato and pigweed seeds.

Time in hours	Concentration of fumigant in mg per liter of air					
	220	176	132	88	44	22
			Tomato			
4	38	30	29	22	9	9
5	72	69	46	38	38	19
6	40	39	44	32	19	16
7	72	52	52	43	12	5
8	92	73	68	59	29	29
10	100	98	93	92	74	45
			Pigweed			
4	75	81	43	68	25	36
5	80	73	58	45	71	59
6	76	69	48	41	22	14
7	93	91	84	81	39	30
8	100	96	94	78	76	64
10	100	100	100	100	94	66

Table 3. Influence of time and concentration of chloropicrin vapors on percent kill of tomato and pigweed seeds.

Time in hours	Concentration of fumigant in mg per liter of air					
	220	176	132	88	44	22
	Tomato					
4	81	75	65	56	49	31
6	96	95	93	86	73	47
8	100	100	91	96	77	47
10	100	100	100	99	88	58
12	100	100	100	100	89	65
	Pigweed					
4	54	74	61	44	36	33
6	84	86	56	47	10	4
8	100	100	99	77	56	0
10	100	100	100	100	75	47
12	100	100	100	99	73	30

Table 4. Influence of time and concentration of allyl alcohol vapors on percent kill of tomato and pigweed seeds.

Time in hours	Concentration of fumigant in mg per liter of air			
	2.6	1.3	0.70	0.35
	Tomato			
1	100	99	90	83
2	100	99	97	88
3	100	98	98	96
4	100	100	100	100
	Pigweed			
1	100	100	100	100
2	100	100	100	99
3	100	100	100	100
4	100	100	100	100

Allyl alcohol was the most toxic fumigant studied giving 100 percent kill at very low concentrations for short time intervals. Next in activity was 1,3–dichloropropene. Sodium N–methyldithiocarbamate dihydrate (SMDC) and chloropicrin were lowest in activity, requiring 8 to 10 hours exposure at the highest concentration used (220mg/L) for 100 percent kill.

Discussion

It is evident from the data presented that for the control of dormant imbibed seeds a strong relationship exists between the time of exposure and the concentration of fumigant used. Many combinations of concentration and exposure time will produce 100 percent kill. This same relationship has been reported for nematode control with soil fumigants (1, 2, 3) and for injury to dry seeds from CS_2 fumigation (5).

Whether fumigants enter the seeds in vapor or liquid form is not known. Of those used, 1,3–dichloropropene, chloropicrin, and the decomposition products of SMDC are soluble in water to the extent

of only one to two milligrams per liter whereas allyl alcohol is completely water soluble. The imbibed seed has a layer of water around the seed coat and whether the greater toxicity of allyl alcohol is due to water solubility alone is not known. With fumigants that are only slightly water soluble the concentration in the water film may still be sufficient to be toxic. If it is not, then the fumigant entering the seed in a combination of the water-soluble and gaseous forms may be be lethal. To which phase the lethal effect can be attributed remains to be determined. The relative toxicity of these fumigants in soil may be entirely different from that in the atmosphere, due to the necessity of vapor diffusion and the adsorption of the materials by the soil.

The low activity of SMDC may be partially due to the fact that it must be broken down to release the toxicant (3). Whether this occurs by hydrolysis alone is not definitely known. Moisture has been shown to be instrumental and in this experiment the only moisture that was present was in the fumigant solution itself and in the atmosphere (90–100 percent). If the inclusion of soil or of moisture in the free state would increase its action is not known.

The possible importance of vapor pressure in speed of action of fumigants should be considered. The vapor pressure at 20° C. for chloropicrin, 1,3–dichloropropene and allyl alcohol is 18.3, 38, and 17.3 mm. of mercury respectively. The action of the latter two fumigants against tomato and pigweed seeds was much more rapid than for chloropicrin yet the vapor pressures are similar. One could conclude that some factor other than vapor pressure must be responsible for the speed of action.

SUMMARY

For control of dormant imbibed seeds, a short time exposure at a high concentration of fumigant or a long exposure at a low concentration was required.

When the concentration of any fumigant was increased at a specified time of exposure, the percent kill of tomato and pigweed seeds was increased. Likewise, at any one concentration, if the time was increased the percent kill also increased.

Allyl alcohol was the most toxic of the fumigants studied. Next in activity was 1,3–dichloropropene while SMDC and chloropicrin were least active.

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Weed Control in Cotton Over a Ten-year Period by Use of the More Promising Materials and Techniques[1]

VERNON C. HARRIS[2]

IN 1950 an experiment was initiated at Mississippi State University to evaluate the comparative efficiency of certain promising herbicides in controlling weeds in cotton. The use of herbicides for weed control in cotton was beginning to be accepted as an agricultural practice. Results from a long-time experiment involving the use of herbicides for weed control in cotton were needed.

The objectives of the study were (1) to control weeds in cotton by means other than the hoe and thereby complete the mechanization of the production of cotton; (2) to test under field conditions certain weed control procedures in cotton and to evaluate weed-control costs and production; and to (3) field evaluate some selected herbicides alone and in combination, applied as pre-emergence and post-emergence treatments, for the control of weeds in cotton, with emphasis on economic aspects.

The experimental results for 1950–53 have been reported.[3]

MATERIALS AND METHODS

The experiment was conducted on a Kaufman clay loam at Mississippi State University, State College, Mississippi. The harvest season of 1959 ended the tenth year in which the same field plots had received herbicidal treatments or other weed-control practices.

LHO-1,[4] [5a] 4, 6-dinitro-*o-sec*-butylphenol (DNBP)[b] and 3-(*p*-chlorophenyl)-1,1-dimethylurea (monuron),[c] were the first herbicides evaluated in the study. The discovery of new and better herbicides resulted in the omission of some and the addition of others. Isopropyl *N*-(3-chlorophenyl) carbamate (CIPC),[d] 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron), and 2,4,5-trichlorophenoxyethyl sulfate (2,4,5-TES)[e] were included in the study in 1954. The herbicide N-(3,4-dichlorophenyl) methylacrylamide (Dicryl)[f] was included in the study in 1959. DNBP, 2,4,5-TES, and monuron were applied as pre-emergence herbicides only. CIPC and diuron were tested as pre-emergence and post-emergence herbicides. LHO-1 and *N*-(3,4-dichlo-

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[3]Harris, V. C. Some residual aspects of using DNOSBP and LHO-1 for weed control in cotton for four years on a clay loam soil. Proc. SWC 7:105–114. 1954.

[4]LHO-1–a herbicidal oil with a boiling range of 305–410°F, aromatics 22-24%, maximum aniline point 128°F.

[5]The author wishes to acknowledge the cooperation of the Lion Oil Company,a the Dow Chemical Company,b E.I. duPont de Nemours and Company,c the Columbia-Southern Chemical Corporation,d the Union Carbide Chemicals Company,e and the Niagara Chemical Division,f for supplying the experimental compounds included in these investigations.

rophenyl) methylacrylamide were applied as post-emergence treatments. The hand-hoed and non-hoed plots were rotated each year.

A routine procedure for preparing the land and the seed-bed was practiced each year. The cotton stalks were cut in the fall, and the land was disked or flat broken. In the spring approximately 1,000 lb/A of a mixed fertilizer were applied broadcast and disked in. The land was then bedded into 40-inch row-widths ready for planting. The seed-bed was harrowed or disked lightly each year just prior to planting and application of the pre-emergence herbicides.

The cotton seed were planted 1 inch deep, and pre-emergence herbicidal treatments were applied in the same operation using a one-row tractor. During the 10-year period Empire, Coker 100 Wilt, Delfos 9169, Delta and Pine Land 15, Delta and Pine Land Fox, and Rex cotton were the varieties used. The seed were hill-dropped, planted 8 to 10 seed per hill, and spaced 10 inches apart in the row. The herbicides were applied to a 12-inch band centering the cotton row. The cotton was replanted in 1952, 1953, 1954, and 1959.

Post-emergence herbicides were applied by using tractor equipment in most years. In 3 of the 10 years the application was made with a 3-gal compressed air hand sprayer.

The plots consisted of four rows 65 feet long. Treatments were replicated three times and randomized within blocks. Plots treated with herbicides were on the same location each year, but the hand-hoed and non-hoed plots were on different locations each year. The hand-hoed and non-hoed plots were rotated each year to prevent build-up of weed populations on the non-hoed plots.

The untreated area between the rows was kept free of weeds by post-emergence cultivations. These cultivations were made approximately 6 times a year by use of tractor equipment. The equipment consisted of disk hillers, scratchers with and without fenders attached, and sweeps. In 1950 and 1951 the fenders were removed and soil was thrown into the treated band after the third cultivation for the control of small weeds. All plots received uniform cultivations, fertilization, and insecticide applications. An average of 10 insecticide applications was made each year for the control of the boll weevil. Furrow irrigation of the cotton was superimposed on the test in 4 of the 10 years. The cotton was defoliated in 3 of the 10 years. In 8 of the 10 years all plots were planted to a cover crop (vetch, crimson clover, wild winter peas, or Austrian winter peas).

Weather conditions were mostly favorable each year at time of planting. Rain occurred between planting and emergence of the cotton in 8 of the 10 years. Two years were dry and hot, 5 were near normal, and 3 had excessive rainfall in the spring and fall. Adverse weather after planting was largely responsible for the loss of cotton stand, which made replanting necessary in 4 years.

Data on weed control and crop-plant injury were taken several times each year. Ratings of excellent, good, fair, and poor were used for weed-control evaluations. These weed-control ratings were based

on visual ratings by comparing all replicates of each treatment with the check.

Crop-plant injury was described as none, moderate, severe, or killed.

Yields of seed cotton were obtained by hand-picking and weighing the cotton from each replicated plot, and computing means for tabulations.

RESULTS AND DISCUSSION

Tables 1 (1950), 2 (1955), and 3 (1959) contain data selected from the study.

The herbicidal treatments presented an ever changing picture (Tables 1, 2, and 3), but the hoed check and non-hoed check were constant. The cotton stand was not seriously influenced by any treatment. Cotton plants were affected by DNBP, diuron, and *N*–(3,4-dichlorophenyl) methylacrylamide. DNBP caused moderate to severe stunting and burning of the hypocotyls. Cotton plants responded to diuron treatments by discoloration of the cotyledons and the first primary leaves. These were usually yellow to partly yellow. *N*-(3,4-dichlorophenyl) methylacrylamide caused severe stunting of the cotton plants, and the leaves turned light green.

Weed-control ratings were from poor to excellent, depending upon treatment and rate per acre. The rates of herbicides given in the experiment are band application rates and not broadcast application rates. DNBP at 3 lb/A plus 7 gallons LHO-1 resulted in good to excellent weed control over the 10-year testing period. LHO-1 at two post-emergence applications per year (7 and 5 gal/A) gave fair to good weed control. CIPC at 2 lb/A on a 12-inch band resulted in excellent control of crab-grass and poor control of pigweed.

Diuron at 1 lb/A pre-emergence plus 1 lb/A post-emergence resulted in excellent weed control and was the superior treatment in the test. *N*-(3,4-dichlorophenyl) methylacrylamide applied 1 lb/A as overhead spray on cotton and weeds resulted in good kill of emerged weeds. Data from other experiments indicated that three applications of *N*-(3,4-dichlorophenyl) methylacrylamide were necessary for season-long weed control in cotton. The hand-hoed check was rated excellent in weed control and was used as a basis for weed control ratings of other treatments. The non-hoed check was rated poor in weed control. The cost of hand-hoeing for weed control varied somewhat from year to year. The yield of seed cotton per acre varied somewhat between treatments. Yields were not significantly different on the plots where hand-hoeing and herbicides were used for weed control. The number of hours and cost of spot hoeing were directly correlated with lack of initial weed control or poor control of a particular weed (Tables 1, 2, and 3).

The data in Table 4 were taken from the best treatment each year during the 10 years. The plots treated with herbicides yielded more cotton per acre than the hand-hoed check in 2 years of the 10. The hand-hoed plots averaged 142 lb/A more seed cotton per year

Table 1. Effect of two herbicides alone and in combination applied pre-emergence and post-emergence for the control of weeds in cotton, 1950.

Treatment	Rate/A on 12-inch band	Per cent stand of cotton	Cotton plant injury	Weed control ratings[a]	Cost of ($) weed control (actual cost of herbicide or hoeing)	Yield seed cotton, lb/A
1. DNBP pre-	4 lb	95	none	fair	6.40	900
2. DNBP pre-	6 lb	95	none	fair	9.60	1540
3. DNBP pre-	8 lb	95	moderate burning of cotyledons and some stunting	excellent	12.80	1530
4. DNBP pre- + LHO-1 post-	3 lb + 7 gal oil	95	none	excellent	6.60	1960
5. DNBP pre- + LHO-1 post-	1 lb + 7 gal oil	95	none	fair	3.40	1700
6. LHO-1 post-	7 gal oil + 7 gal oil	95	none	good	3.50	1720
7. Hoed check	35 hr @ 40c ph	95	none	excellent	14.00	2010
8. Non-hoed check, received standard cultivation	0	95	none	poor	0.00	5

[a]Weeds were: *Digitaria sanguinalis* (crab-grass), *Sida spinosa* (sida), *Amaranthus graecizans*, *A. palmeri*, and *A. retroflexus* (pigweed), *Ipomoea purpurea* (morning-glory).

Table 2. Effect of some selected herbicides alone and in combination applied pre-emergence and post-emergence for the control of weeds in cotton, 1955.

Treatment	Rate/A on 12-inch band	Per cent stand of cotton	Cotton plant injury	Weed control ratings	Cost ($) of weed control (actual cost of herbicide or hoeing)	Yield seed cotton lb/A	Spot hoeing per acre	
							Hours	Dollars
1. CIPC pre–+ LHO–1 post–	2 lb +7 and 5 gal oil	95	none	poor on pigweed, good on crabgrass	6.50	2100	9	3.60
2. CIPC pre + CIPC post–	2 lb + 2 lb	95	none	poor on pigweed, excellent on crabgrass	7.00	2250	3	1.20
3. CIPC post–	2 lb	95	nome	poor on pigweed, good on crabgrass	3.50	2550	12	4.80
4. DNBP pre–+ LHO–1 post–	2 lb +7 and 5 gal oil	80	severe to moderate stunting and burning of hypocotyls	good on pigweed and crabgrass	4.80	2050	5	2.00
5. Diuron pre–+ LHO–1 post–	1 lb + 5 gal oil	85	some stunting and yellowing of first leaves	excellent	7.30	2150	3	1.20
6. Diuron pre–+ diuron post–	1 lb + 1 lb	95	some stunting and yellowing of first leaves	excellent	12.00	2200	0	0.00
7. 2,4,5-TES pre– +LHO–1 post–	1 lb + 5 gal oil	95	none	excellent	3.80	2350	0	0.00
8. LHO–1 post–	7 and 5 gal oil	95	none	fair	3.00	2450	9	3.60
9. Hoed check	36 hr @ 60c hr	95	none	excellent	21.60	2500	2	.80
10. Non-hoed check, received standard cultivation	0	95	none	poor	0.00	400	0	0.00

Table 3. Effect of some selected herbicides alone and in combination applied pre-emergence and post-emergence for the control of weeds in cotton, 1959.

Treatment	Rate/A on 12-inch band	Per cent stand of cotton	Cotton plant injury	Weed control ratings	Cost ($) of weed control (actual cost of herbicide or hoeing)	Yield seed cotton lb/A	Spot hoeing per acre	
							Hours	Dollars
1. CIPC pre–+..... LHO–1 post–.....	2 lb+7 and 5 gal oil	95	none	excellent	6.50	1840	13	6.50
2. CIPC pre–+..... CIPC post–.....	2 lb+ 2 lb	95	none	good	7.00	1970	11	5.50
3. CIPC post–.....	2 lb	95	none	fair	3.50	1800	15	7.50
4. DNBP pre–+..... LHO–1 post–.....	2 lb+7 and 5 gal oil	95	none	excellent	4.80	1970	12	6.00
5. Diuron pre–+ *N*-(3,4-dichlorophenyl) methylacrylamide post–	1 lb+ 1 lb	90	moderate to severe stunting	excellent	7.30	1770	6	3.00
6. Diuron pre–+..... diuron post–.....	1 lb+ 1 lb	90	moderate stunting and yellowing of leaves	excellent	12.00	1940	4	2.00
7. *N*-(3,4-dichlorophenyl) methylacrylamide post– overall	1 lb	95	moderate to severe stunting	good	—	1700	11	5.50
8. [illegible]–1 post–+*N*–[illegible]chlorophenyl) [illegible]acrylamide post– overall	7 gal oil + 1 lb	95	moderate to severe stunting	fair	3.00	1770	13	6.50
9. Hoed check.....	17 hr @ 50c hr	95	none	excellent	8.50	2070	5	2.50
10. Non-hoed check, received standard cultivation	0	95	none	poor	0.00	950	0	0.00

Table 4. A comparison of chemical weeding, hand-weeding, and no weeding of cotton over a 10-year period.[a]

Treatment[b]	Year	Cost ($) of weed control (herbicide on 12-inch band or hoeing)	Cultivation of sides and middles of rows		Yield (lb/A) of seed cotton	Returns ($) per acre[c]	
			Times	Cost ($)		Gross	Net
1. Pre- and post-emergence herbicide	1950	6.60	7	7.00	1960	273.70	260.20
2. Hand-hoed	1950	14.00	7	7.00	2010	280.70	259.70
3. Check—sides and middles cultivated	1950	0.00	7	7.00	6	0.85	−6.20
1.	1951	8.80	7	7.00	3110	403.80	388.00
2.	1951	18.00	7	7.00	3610	468.80	443.80
3.	1951	0.00	7	7.00	1000	130.00	123.00
1.	1952	8.30	8	8.00	1970	216.20	199.90
2.	1952	24.10	8	8.00	2020	221.70	189.60
3.	1952	0.00	8	8.00	280	31.10	23.10
1.	1953	7.00	5	5.00	2230	244.80	232.80
2.	1953	21.40	5	5.00	2300	253.20	226.80
3.	1953	0.00	5	5.00	470	51.90	46.90
1.	1954	4.80	6	6.00	1600	176.00	165.30
2.	1954	12.40	6	6.00	1830	201.30	182.90
3.	1954	0.00	6	6.00	700	77.00	71.00
1.	1955	4.80	5	5.00	2050	225.50	215.80
2.	1955	21.60	5	5.00	2500	275.00	248.40
3.	1955	0.00	5	5.00	400	44.00	39.00
1.	1956	4.80	5	5.00	2290	228.50	218.80
2.	1956	12.50	5	5.00	2520	251.50	234.00
3.	1956	0.00	5	5.00	80	7.50	2.50
1.	1957	7.30	6	6.00	1920	211.20	199.00
2.	1957	9.00	6	6.00	1800	198.00	185.00
3.	1957	0.00	6	6.00	190	20.40	15.40
1.	1958	7.30	5	5.00	2050	225.50	212.40
2.	1958	8.00	5	5.00	1900	209.00	196.00
3.	1958	0.00	5	5.00	350	38.50	35.00
1.	1959	4.80	6	6.00	1970	255.80	245.10
2.	1959	8.50	6	6.00	2070	267.80	253.30
3.	1959	0.00	6	6.00	950	124.00	118.00
Ten-year average 1950–1959							
1.	——	6.40	–	6.00	2110	246.10	233.70
2.	——	14.90	–	6.00	2250	262.70	242.00
3.	——	0.00	–	6.00	440	52.50	46.50

[a]Practices were done on a 12-inch band centered over the drill, RCB, and replicated. Fertilization, cultivation of sides and middles, and insect control were standard in all treatments.

[b]1. Received a pre- and a post-emergence herbicide on 12-inch band plus regular cultivation of sides and middles.

2. Received no herbicide, was hand-hoed plus regular cultivation of sides and middles.

3. Received no herbicide or hand-hoeing on the 12-inch band, but was cultivated on sides and middles.

[c]These figures refer to returns less the cost of weed control practices and do not include spot hoeing, cost of fertilizer, insecticides, etc.

than those treated with herbicides and grossed $16.60 more per acre, or a net difference of $8.26. The analysis of variance for yields indicated that there was a significant difference, at the 10% level of probability, between the average yield per acre obtained by hand-hoeing as compared with weed control by the use of herbicides.

The cost of herbicides to weed an acre of cotton was $6.40, which was $8.54 cheaper than hand-hoeing.

The cost of weeding cotton by herbicides was 2⅛ cents per pound of lint cotton produced, and the dollar return was 17 to 1 (Table 5). The cost of hand-hoeing was 3¼ cents per pound of lint cotton produced, and the dollar return was 11 to 1. The cost of weed control by the use of cultivation alone was 4½ cents per pound of lint cotton produced, and the dollar return was 8 to 1. Weed control with herbicides returned $6 more per dollar invested for weed control than hand-hoeing.

Table 5. The economic aspects of using herbicides or hand-hoeing for weed control in cotton.[a]

Treatment	Total[b] cost/A	Total yield seed cotton/A	Total yield lint cotton/A	Total net returns	Average cost of weed control/lb lint cotton	Average net return for each dollar invested in weed control
	Dollars	Pounds	Pounds	Dollars	Cents	Dollars
1. Pre- and post- emergence herbicide on 12-inch band plus regular cultivation of sides and middles...	136.60	21,120	6,420	2,336.90	2⅛	17.00
2. Hand-hoed on 12-inch band plus regular cultivation of sides and middles...	222.40	22,540	6,830	2,419.40	3¼	11.00
3. Check—sides and middles cultivated, received no herbicide or hand-hoeing on 12-inch band....	60.00	4,410	1,340	465.20	4½	8.00

[a]Figures are totals for 10 years, 1950–1959.
[b]Cost of herbicides or hand-hoeing plus cost of cultivation of sides and middles of rows.

The analysis of variance for net returns indicated that the difference was not significant at the 10% level of probability between the average net return per acre when hand-hoeing was compared with chemical weed control.

SUMMARY AND CONCLUSIONS

Weeds were satisfactorily controlled in cotton by the application of a pre-emergence and a post-emergence herbicide. The cost of the herbicide for weed control was less than the cost of hand-hoeing. The hand-hoeing treatment resulted in slightly higher cotton yields and net returns than the combination pre- and post-emergence herbicide treatment, but not significantly so. The combination herbicide treatment and the hand-hoeing treatment were significantly better than cultivation alone.

A pre-emergence herbicide gave weed control for four to six weeks. Weeds were controlled from then on by the application of a post-emergence herbicide. Some spot hoeing was necessary eight out of the ten years. The superior treatment from all angles was diuron pre- and post-emergence at 1 lb/A.

Weeds were effectively controlled in cotton with herbicides at little or no reduction in cotton yield. The herbicides used did not permanently contaminate or accumulate in the soil, and in adverse weather they greatly reduced weed losses and made it possible to save the crop. The return per dollar invested for weed control was greatest ($17) when herbicides were used for weed control. The cost of weed control for each pound of lint cotton produced was 1⅛ cents per pound cheaper when herbicides were used to control weeds.

N-(3,4-dichlorophenyl) methylacrylamide applied as a directed spray exhibited promise as a post-emergence herbicide for weed control in cotton in the 1959 study.

Kill of Blue Oak and Poison Oak by Aircraft Spraying with Phenoxy Herbicides

O. A. LEONARD[1] and C. E. CARLSON[2]

BLUE oak *(Quercus douglasii)* is a common tree on several million acres of grazing land in California. It may occur as pure stands, but other species of woody plants, especially poison oak *(Rhus diversiloba)*, are commonly associated with it. Leonard (3) and Harvey, et al. (2) reported the effectiveness of the cut-surface method using 2,4–D amine for killing blue oak. Unfortunately, killing of the blue oak results in a "release" of some of the under-story shrubs, which may become a problem later. A broadcast spray that will control all the woody plants is needed.

METHODS AND MATERIALS

The plots were located in the central Sierra foothills near Sutter Creek, California. Blue oak and poison oak were the most abundant woody plants present; however, interior live oak *(Quercus wislizenii)*, manzanita *(Arctostaphylos manzanita)*, buckeye *(Aesculus californica)*, and digger pine *(Pinus sabiniana)* were present in varying numbers on different plots.

The plots were laid off in such a manner as to make a study of reapplication possible. Each plot consisted of 24 flight strips, each 35 feet wide and 1000 feet long. The large plots were divided into sub-plots for a study of retreatment. There was an untreated strip 210 feet wide between each major plot.

The herbicides used in these tests were water soluble amines and the propylene glycol butyl ether (PGBE) esters of 2,4-dichlorophenoxyacetic acid (2,4-D), 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), 2-(2,4-dichlorophenoxy) propionic acid 2-(2,4-DP), and 2-(2,4,5-trichlorophenoxy) propionic acid (silvex)[3].

The spray applications with amine formulations were applied on May 10, 1955 and May 10, 1956. The esters were applied on May 10 and June 10, 1955, May 10 and June 8, 1956, and May 15, 1957. The applications in May were made with a Piper Super Cub and the June applications with a Stearman biplane. All applications were 2 pounds acid equivalent per acre applied in a volume of 10 gallons (except for May 15, 1957, when 5 gallons were used), containing 1 gallon of diesel oil (ester treatments) or 1 gallon of emulsifiable oil (amine treatments). Hydrogen filled balloons were used in the flagging. Spraying was done as early in the morning as possible, with wind velocities less than 5 miles per hour.

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[3]The authors wish to acknowledge the cooperation of the Dow Chemical Company in supplying the compounds and paying for the applications.

The two dates of treatment were chosen to correspond to different stages of growth of the blue oak. The May 10, 1955 applications were made about 10 days after the leaves were fully enlarged (slightly later than normal). Shoot growth on the plots to be retreated on May 10, 1956 was markedly retarded, but varied with the severity of the treatment. Because of this, a further retreatment was made on June 8, 1956 of plots which had been sprayed initially on May 10, 1955. The treatments applied on June 10, 1955 were not as damaging as the May treatments, so the growth the following year was closer to normal. The stage of development on May 15, 1957 varied depending upon the previous treatment.

Leaf development of poison oak, buckeye, etc. tended to parallel that of blue oak. Growth on this site was most active between April 5 and June 1, but varied somewhat from year to year. Rainfall averaged about 28.5 inches a year, generally with little rain after May 15.

Data were recorded in 1955, 1956, 1957, and 1959. The final results are regarded as the most significant and are presented. Kill was determined on a 100 foot longitudinal band through the center of each plot.

RESULTS

Blue oak. Single applications of herbicides (esters) resulted in no more than a 20% kill of the blue oaks (Table 1). The activities of 2-(2,4-DP) and silvex were essentially the same for the treatments applied in May; both 2,4-D and 2,4,5-T resulted in kills of 5% or less. Single applications in June were ineffective with all of the herbicides used.

Table 1. The percent reduction in stand of blue oak by single and repeated airplane applications of 2,4-D, 2,4,5-T, 2-(2,4-DP), and silvex (PGBE esters). Results were recorded in May, 1959.

When sprayed					Per cent reduction in stand of blue oak			
5/10/55	6/10/55	5/10/56	6/8/56	5/15/57	2,4–D	2,4,5–T	2–(2,4–DP)	Silvex
x	–	–	–	–	2	5	19	20
x	–	x	–	–	7	5	35	34
x	–	–	x	–	2	6	28	37
x	–	–	–	x	15	20	72	50
x	–	x	–	x	9	35	—	67
x	–	–	x	x	—	—	—	90
–	x	–	–	–	2	0	2	5
–	x	–	x	–	0	3	—	10

Early in this study, it was thought that the trees which were severely injured might die; however, most of these trees survived and appeared to be recovering 4 years after treatment.

Shoot growth was limited when retreatments were applied in May of the second year. This was due to the killing of the smaller branches, with the new shoot growth coming from dormant buds. Shoot growth was least following the May applications of the esters of 2-(2,4-DP) and silvex. Because shoot growth was sparse when the

treatments were applied in May, another portion of the plots was retreated in June. Actual plant kills were increased somewhat by the retreatments with 2-(2,4-DP) and silvex, but the effect of date of retreatment was slight. Retreatments with 2,4-D and 2,4,5-T were ineffective. Retreatment of the plots originally treated in June killed few additional trees.

Skipping a year between treatments resulted in a greater reduction in stand of the blue oak with 2-(2,4-DP) and silvex than spraying on successive years. The kills were 72% with 2-(2,4-DP) and 50% with silvex, as compared with 35% and 34% when sprayed with the same herbicides on successive years. The results further suggest that 2-(2,4-DP) was more effective than silvex when a year elapsed between sprayings. No such advantage in skipping a year between spray applications was evident with 2,4-D and 2,4,5-T; all such treatments were relatively ineffective.

The most effective treatment was silvex applied in May, 1955, with retreatments in June, 1956, and again in May, 1957. The kill was somewhat greater than when silvex was applied in May for 3 successive years. A treatment involving 3 applications of 2-(2,4-DP) was not made because insufficient chemical was available. Neither 2,4-D nor 2,4,5-T applied 3 times resulted in any marked reduction in the stand of blue oak; however, 2,4,5-T was the more effective herbicide.

The amine treatments gave very poor kills of the blue oak. The most effective amine treatment was 2-(2,4-DP), in which 19% of the trees were killed with 2 applications.

Poison oak. The effect of the esters of 2,4-D, etc. on poison oak are shown in Table 2. The results of the June applications and of the amine formulations were omitted because the kills were negligible, even with 2 applications.

Table 2. The control of poison oak by single and repeated airplane applications of 2,4-D, 2,4,5-T, 2(2,4-DP), and silvex (PGBE esters). Ratings[a] in May, 1959.

When sprayed				Rating of effect on poison oak			
5/10/55	5/10/56	5/8/56	5/15/57	2,4–D	2,4,5–T	2–(2,4–DP)	Silvex
x	–	–	–	0	0	0	0
x	x	–	–	4	5	0	8
x	–	–	x	4	7	0	8
x	x	–	x	6	8	–	9
x	–	x	x	–	–	–	8

[a]Relative kill of poison oak, with 10 representing complete control and 0 no control.

The most effective treatment in reducing the stand of poison oak was with silvex applied in May for 3 consecutive years. The regrowth in 1959 was but a fraction of 1% of the growth present before the sprays were applied. It was not possible to determine actual plant kill, because widely separated shoots might have underground connections. It is possible that no more than 75% of the poison oak "plants" or "clumps" were completely killed.

Poison oak was markedly reduced by 2 applications of silvex, whether the second application was made one or 2 years after the first one. Single applications of silvex applied in 1955 appeared completely ineffective, as viewed in 1959.

The herbicide next to silvex in order of effectiveness was 2,4,5-T. Three applications resulted in a considerable reduction in the number of clumps with live shoots. Kills with 2,4-D were inferior to those obtained with 2,4,5-T. The least effective herbicide was 2-(2,4-DP); in fact, the poison oak showed a better growth where blue oak was killed by this herbicide.

Other species. Some interior live oak were killed by 3 applications of silvex, but none were killed by a fewer number of applications; also, no other herbicide was effective in killing a single live oak tree. Digger pine was damaged rather severely by 2,4-D and slightly by 2,4,5-T, but the plants recovered. Silvex and 2-(2,4-DP) did not damage digger pine. Manzanita and buckeye were not present in sufficient quantity to make many comparisons between herbicides. Most of the manzanita were killed by 3 applications of the esters of 2,4-D, 2,4,5-T, and silvex. Buckeye was top killed by 2,4-D (ester) but was only slightly damaged by silvex (ester).

DISCUSSION

Time of application of the phenoxy herbicides on woody plants greatly influenced phytotoxicity. The effective period of application appeared to be much shorter in California than it was in the South, where it ranged from May 15 to July 1 (Peevy and Burns (9)). The general absence of rain in California after May 15 limits the period of effectiveness of the phenoxy herbicides on blue oak and poison oak. The limited period of effectiveness with the phenoxy herbicides on other woody plants has already been reported (4) (6). Silvex and 2-(2,4-DP) were far more effective on blue oak in May than they were in June, with one exception involving a series of 3 applications of silvex, when the first application was in May, the second in June, and the third in May. The control was greater than when the treatments were all applied in May of 3 successive years.

Poison oak, also, was far more sensitive to silvex, 2,4,5-T, and 2,4-D in May than in June. For example, silvex ester applied in May for 2 years reduced poison oak to a very low level, as viewed 3 years after the last application. However, under similar conditions, silvex ester applied in June of successive years resulted in no control.

Foliage applications of the phenoxy propionics were appreciably superior to the phenoxy acetics on blue oak, with 2-(2,4-DP) slightly the more effective in one series of treatments. 2,4,5-T was appreciably inferior to both of these herbicides, while 2,4-D was even less effective. Previous studies by Leonard and Crafts (7) indicated that there was very little translocation of 2,4-D out of blue oak leaves into the stems. This explains why blue oak was not killed by foliage sprays applied by aircraft, even though the trees were readily killed with

2,4-D (amine) applied to cuts in the stems (2) (3). An interesting aspect of these studies was that 2,4-D and 2,4,5-T were both more effective than 2-(2,4-DP) and silvex when applied to cuts in the stems (all amine formulations).

Peevy and Burns (9) in Louisiana found 2,4,5-T ester to be equal to silvex ester on black, blackjack, and post oaks. McIlvain and Armstrong (8), Darrow (1), and Silker and Darrow (10) did not find the advantage of silvex over 2,4,5-T that was noted in the present work. Both chemicals appeared to be appreciably more effective on Louisiana, Texas, and Oklahoma oaks, than they were on the blue oak in California.

The serious absorption and translocation problem which was shown to exist in blue oak leaves with 2,4-D (7) was possibly less severe with 2-(2,4-DP) and silvex and may account for the greater effectiveness of the latter 2 herbicides. Again, translocation difficulties may have been more severe in the blue oak than they were in the Louisiana (9), Texas (1) (10) and Oklahoma (8) oaks. The greater sensitivity of blue oak to silvex and 2-(2,4-DP) in May than in June may be due to a corresponding reduction in absorption and translocation of these herbicides. Such a reduction with season in the absorption and translocation has already been shown with *Baccharis pilularis, Photinia arbutifolia, Quercus wislizenii, Arctostaphylos manzanita* (7). Similar observations have been made with 2,4-D and 2,4,5-T on poison oak (5).

Silvex was the most effective herbicide on poison oak, followed by 2,4,5-T, 2,4-D, and 2-(2,4-DP). Silvex was the most effective chemical on interior live oak; in fact, no herbicide other than silvex killed a single live oak tree. Kills with the esters were markedly superior to those obtained with the amines, especially with the phenoxy propionics. Peevy and Burns (9) also noted that the amine formulations of 2,4,5-T, silvex, and 2-(2,4-DP) were less effective than the ester formulations. Tschirley and Hull (11) found that an ester of 2,4,5-T was consistently more effective than the amine on velvet mesquite under field conditions.

The results presented in this paper were from the first test in which blue oak was appreciably controlled by aircraft spraying. Previous tests with the amine and ester forms of 2,4-D and 2,4,5-T had resulted in relatively poor kills—the same as reported in the present paper. Some aircraft and knapsack sprayer tests involving single applications of 2-(2,4-DP) and silvex had indicated that these herbicides were appreciably more effective on blue oak than either 2,4-D or 2,4,4-T.

CONCLUSIONS

A test of 8 herbicidal treatments for controlling blue oak and poison oak by aircraft spraying was conducted in the central Sierra foothills. Single applications of all herbicides were relatively ineffective on both species. However, some retreatments were moderately effective on one species or the other. Thus, 2 applications of silvex ester applied in May were fairly effective on poison oak, but

somewhat less so on blue oak. On the other hand, an ester of 2-(2,4-DP) was ineffective on poison oak, but more effective than silvex on blue oak. Skipping a year between treatments was more effective on reducing the stand of blue oak than spraying on consecutive years with 2-(2,4-DP) and silvex; however, skipping a year did not enhance the kill of poison oak. Two applications of either 2,4-D or 2,4,5-T resulted in only a slight reduction in the stand of blue oak and poison oak.

The most effective treatment on blue oak and poison oak was with an ester of silvex applied once a year for 3 years. The most effective treatment on blue oak was 3 applications in May, June and May of consecutive years; however, the control of poison oak was greater when the applications were all made in May. The next most effective herbicide applied for 3 consecutive years was 2,4,5-T, and the least effective one was 2,4-D. Three applications of 2-(2,4-DP) were not made.

Time of treatment greatly influenced the results on blue oak and poison oak. All of the more effective treatments involved applications in May. When all of the applications and reapplications were made in June, the kills were negligible.

Amine formulations of 2,4-D, 2,4,5-T, 2-(2,4-DP), and silvex were all relatively ineffective against both blue oak and poison oak, even with reapplication.

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Quackgrass Control in Potato Production[1]

D. R. Isleib[2]

Introduction

Quackgrass, *Agropyron repens*, is the major weed problem on at least half of the acreage planted to potatoes in Michigan. The northern counties of the lower peninsula and much of the upper peninsula have an ideal climate for quackgrass, and potato growers must include control measures in their production plans. The work reported in this paper was directed toward development of an effective and economical control program.

Review of Literature

Mechanical methods have long been employed in the control of quackgrass. In general, summer fallow begun in midsummer of the year preceding the potato crop and continued for six to twelve consecutive cultivations has been common. Such a program was used experimentally by Lowe and Buchholtz (4) who obtained excellent reduction of quackgrass infestation in an alfalfa-timothy sod by six field cultivations beginning in mid-July. These authors recognized the importance of favorable weather to the success of their treatment. They found little value in supplemental nitrogen fertilization as an adjunct to cultivation, and rated smother crops as a decidedly inferior means of control.

More recently, several herbicides toxic to quackgrass have been developed and suggested for its control. Sodium trichloroacetate (TCA) was the first chemical to incorporate both a high level of toxicity and specificity for grasses. Maleic hydrazide (MH) also combines these characteristics. The advent of 2,2-dichloropropionic acid (dalapon) and its derivatives has provided an effective and economical "agronomic tool" for field control of quackgrass.

Buchholtz and Peterson (2) described quackgrass control by fall or early spring application of dalapon to living foliage followed by tillage. Barrons (1) further investigated fall application of dalapon, and concurred with Buchholtz and Peterson in classifying potatoes as relatively tolerant to this chemical. More recently, Cunningham and Trevett (3) investigated pre-emergence applications of dalapon for annual grass and quackgrass control. They cautioned against use of dalapon on potatoes to be used as seed because of the possibility of reduced vigor in seed from sprayed fields.

Materials and Methods

A dense quackgrass sod customarily mowed for hay was used as the experimental area at the Lake City Experiment Station, Lake City,

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Michigan. The soil was a sandy loam. Except when nitrogen top dressing was an experimental variable, the entire area received 50 lb/A of nitrogen before growth started in the spring. Herbicides were applied with a hand-operated sprayer in a volume of 50 gpa. Tillage, planting, field operations, and harvesting were performed with the regular production machinery. Quackgrass survival was estimated by harvesting the foliage from duplicate 20 sq ft quadrats in each plot. Potatoes were dug by machine, hand picked, and machine graded. Total yield, yield of U.S. No. 1 tubers, and specific gravity of tubers from each plot were determined.

Plots were four rows (3 feet apart) by 36 feet. The experimental designs were randomized complete blocks with four, five, or six replications.

In 1955, the sod was sprayed May 18 when new growth approximately 12 in. long was present. Treatments were: no herbicide, 10 lb/A dalapon, 20 lb/A TCA, and 4 lb/A MH. On May 27 the area was field cultivated, plowed, and planted. Half of each four-row plot received normal (3 times) cultivation after emergence of potato plants while the other half was cultivated once. A severe drought occurred during the 1955 growing season, and the potato crop failed on many unirrigated fields in northern Michigan. The plots were not irrigated in 1955.

A split-plot design was used in 1956 and 1957. Sub-plots received 0 and 40 lb/A of nitrogen. Main plots in 1956 consisted of untreated controls, 10 lb/A dalapon, 15 lb/A dalapon, and 20 lb/A TCA. Nitrogen was applied May 3, when new leaves of the quackgrass were about 4 in. long. Herbicides were applied May 25, when the nitrogen-fertilized quackgrass was 3 to 4 inches taller, darker green, and more vigorous than that in the unfertilized sod. The sod was field-cultivated, plowed, and planted on June 7. All plots received uniform cultivation and irrigation. Quackgrass was harvested on October 5, potatoes October 6.

Treatments of 5, 7.5, and 10 lb/A dalapon were applied in 1957. Nitrogen was applied in early May, herbicide applications on May 24, and the area field-cultivated, plowed, and planted on June 3. Limited irrigation was available. Quackgrass harvest was made on July 15, and potato harvest on October 12.

A split-plot design was again used in 1958, with sub-plots consisting of either a single field cultivation or four field cultivations preceding plowing and planting. Treatments were a check, 5 and 10 lb/A of dalapon. Uniform nitrogen top-dressing was applied April 7, dalapon April 23, and the entire area field-cultivated May 2. Subsequent field cultivations were May 6, 9, and 12. The entire area was plowed May 12 and planted May 13. Limited irrigation was available. Quackgrass was harvested in early August, and potatoes September 23.

RESULTS AND DISCUSSION

The results are presented in Tables 1, 2 and 3. Both TCA and dalapon in combination with normal row cultivation resulted in

excellent control of quackgrass. Maleic hydrazide failed to control the weed. Quackgrass control was improved by increasing the preplanting field cultivations from one to four, and by increasing postemergence row cultivations from one to three. In general, herbicide treatments resulted in improved yield when compared with unsprayed controls, and there was generally no yield advantage for any one herbicide treatment compared with other treatments. Specific gravity did not respond to herbicide treatment or quackgrass control. Nitrogen applied to the quackgrass prior to spraying did not cause

Table 1. Yield of U. S. No. 1 Sebago potatoes from quackgrass control experiment, Lake City, Michigan, 1955.

Treatment	Cwt. per acre
No herbicide	10
10 lb/A dalapon	38
20 lb/A TCA	20
4 lb/A maleic hydrazide	25
L.S.D. .05	17

Table 2. Yield and specific gravity of U. S. No. 1 Sebago potatoes, and yield of quackgrass at Lake City, Michigan, 1956 and 1957.

Treatment	Yield cwt/A		Specific gravity of tubers		Green quackgrass leaves, lb/A	
	40 lb/A N	No N	40 lb/A N	No N	40 lb/A N	No N
			1956			
No herbicide	105	127	1.070	1.074	5540	3780
10 lb/A dalapon	232	209	1.070	1.076	282	193
15 lb/A dalapon	219	186	1.072	1.074	220	139
20 lb/A TCA	178	187	1.070	1.072	125	38
Mean	184	177	1.070	1.074	1542	1038
			1957			
No herbicide	50	68	1.074	1.072	795	1081
5 lb/A dalapon	190	215	1.075	1.074	144	168
7.5 lb/A dalapon	329	229	1.074	1.074	131	107
10 lb/A dalapon	322	258	1.075	1.073	144	179
Mean	223	192	1.074	1.073	303	384

Table 3. Yield and specific gravity of U. S. No. 1 Russet Rural potatoes, and yield of quackgrass at Lake City, Michigan, 1958.

Treatment	Yield of U.S. No. 1 tubers cwt/A		Specific gravity of tubers		Green quackgrass leaves lb/A	
	One cult.	Four cult.	One cult	Four cult.	One cult.	Four cult.
No herbicide	138	156	1.071	1.072	14830	6730
5 lb/A dalapon	175	178	1.071	1.071	1723	1110
10 lb/A dalapon	178	178	1.073	1.073	3210	369
Mean	164	171	1.072	1.072	6588	2736

a significant improvement in weed control. In 1956, nitrogen application reduced specific gravity and increased weight of live quack-

grass leaves in October. No significant yield response to the 40 lb/A nitrogen application in early spring was observed. In 1957, yield response to 5 lb/A of dalapon was significantly smaller than to 7.5 or 10 lb/A despite equivalent weed control. The apparent increase in yield from nitrogen top dressing in 1957 was not significant. Yield was not increased in sprayed plots in 1958, nor did yield respond differentially to the two cultivation schedules. During 1958, 5 lb/A of dalapon was equally as effective for weed control as 10 lb/A, but the combination of 10 lb/A of dalapon with 4 cultivations resulted in outstanding reduction of weed infestation even though the dalapon x herbicide interaction was not significant.

In three of the four years' trials, practices which controlled quackgrass resulted in increased potato yields. Ten lb/A of dalapon applied to new weed growth in early spring resulted in good weed control and maximum yield in each experiment, although yield and weed control were not necessarily better at the ten pound application rate than at other treatment levels. No justification for supplemental nitrogen top dressing to improve weed control was found in these experiments. Experience showed that a single field cultivation preceding plowing and planting left a fibrous mass of quackgrass residue which made row cultivation and digging difficult. Additional field cultivations before plowing did much to alleviate this condition.

The success of the various combinations of control measures on this dense sod has been duplicated on fields in normal potato rotations. No unfavorable potato response to dalapon has been observed in these trials, although in other experiments reduction in the color of red varieties has been noted. Also, emergence and post emergence applications have been observed to reduce yield in studies in Michigan.

SUMMARY

1. Quackgrass was controlled effectively by application of dalapon to growing leaves in early spring followed in seven to ten days by field cultivating, plowing and planting. Yields of potato tubers were increased where quackgrass was controlled chemically compared with areas which were cultivated only.

2. Supplemental nitrogen applied in early spring as a top dressing did not increase quackgrass control. The extra nitrogen had an expected stimulatory effect on potato growth, although yield increases did not reach levels required for significance at the 0.05 probability level.

3. Mechanical cultivation, both before planting and after crop emergence, increased the control obtained with herbicide treatments. Under the severe conditions of quackgrass infestation of these experiments, four field cultivations before plowing were better than a single field cultivation (1958), and four row cultivations were better than a single row cultivation after emergence (1955).

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Factors Affecting the Competitive Ability of Foxtail Barley *(Hordeum jubatum)*[1]

H. P. Cords[2]

Foxtail barley (*Hordeum jubatum* L.) is a native, short-lived perennial bunch grass with a wide distribution in the United States (3). Hay containing the mature spikes can cause severe injury or death to animals fed upon it because of the barbed awns, which work their way into the face and mouth, opening the way for infections (2).

In Nevada and other Western states, foxtail is particularly prevalent in native pastures and meadows. These usually have a high water table and are frequently saline and/or alkaline. In this study, an attempt has been made to find some of the ways in which these and other factors affect competition between foxtail and more desirable forage species.

Materials and Methods

Germination studies.

During the winter of 1954–55, an experiment to measure the effect of storage conditions on the germination of foxtail seed was performed. The conditions were (a) dry storage, (b) storage in water and (c) storage in water-saturated sand. Two temperatures, 10° and 35°F, were used at each moisture level. Twelve 100-seed samples were stored under each of these conditions. Four samples were removed for germination tests after one week; another four were removed after two weeks; the final four were removed and placed in the germinator after four weeks. Germination was at 20°C in the light.

Greenhouse water table studies.

During the winter of 1954–55 four series of metal cylinders were filled with soil and placed in a tank of water in such a manner that the water level was maintained at 2, 4, 6, and 18 inches below the soil surface. The soil used was a non-saline, nearly neutral silty clay mixed half and half with sand. These soils were saturated with water and allowed to settle. More soil was added whenever necessary in order to rebuild the surface to the desired level. After settling had ceased, seedlings of foxtail were obtained by germinating seed on moist filter paper in petri dishes. These were planted, one to a cylinder. The seedlings were allowed to grow until the plants flowered. At that time the top growth was removed at the crown

[1]Contribution from the Nevada Agr. Exp. Sta. These studies were part of Regional Project W-11, Physiological and Ecological Factors Related to Weed Control.

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and the roots were carefully separated from soil by washing. Shoots and roots were oven dried and weighed.

During the winter of 1955–56, this procedure was repeated with the exception that two soils were used—one saline-alkaline (electrical conductivity of saturation extract 10.0 millimhos per cm^2 and pH 8.8), the other non-saline and non-alkaline (conductivity=0.5, pH 6.8). Also, the water table levels used were 1, 6, 12, and 18 inches rather than as previously described. All other procedures were the same as before.

Field phytometers.

During the spring of 1955 a bank of 14 field phytometers was established. These consisted of 55 gallon drums buried with only the top four inches above the soil surface. The bottom few inches were filled with gravel to promote drainage, and the remainder was filled to within six inches of the top with a sandy loam soil. Circular sod slabs to fit the drums were then taken from a native pasture infested with foxtail. They were selected for uniformity and to contain approximately half foxtail and half spikesedge (*Eleocharis* sp.). Small amounts of other species were present. The sod pieces were trimmed to a thickness of four inches and placed in the drums without further disturbance. At this point, automatic water level controls modified from those described by Allison and Reeve (1) were fitted to each phytometer and seven different water table regimes were established in duplicate. These were (a) at the surface, (b) at three inches, (c) at 18 inches, (d) at 24 inches, (e) drained completely, (f) alternating between the surface in the spring and 18 inches the remainder of the season, and (g) alternating between the surface in the spring and 24 inches the remainder of the season. Regular surface irrigations were applied to those treatments with water table levels below three inches. Owing to unavoidable circumstances, the alternating treatments did not begin until the spring of 1956 and no surface irrigations were made for a period of six weeks during the summer of 1955.

In the spring of 1956 a second series of 12 phytometers was established, six filled to within two inches of the surface with the sandy loam soil previously described and six filled with a saline-alkaline soil from the same source as that used in the greenhouse study. All were fitted with automatic water-level controls with water tables at three, six, and twelve inches within each soil type. When water tables were established and the soils had settled, each phytometer was seeded with 50 seeds each of tall wheatgrass, tall fescue, and foxtail barley plus 100 seeds of strawberry clover. The surface of each was then kept moist by surface irrigation until emergence was complete.

A randomized complete block design was used. Those phytometers with six and twelve-inch water levels received regular surface irrigations.

Fertility and salinity studies.

A greenhouse study was begun in September, 1955, involving

foxtail planted in competition with tall wheatgrass and tall fescue. Two soils were used, one saline-alkaline, the other non-saline and neutral, as previously described. Each was included at two levels of nitrogen (none added and 100 pounds N per acre as ammonium sulfate) and two levels of phosphate (none added and 100 pounds P_2O_5 per acre as superphosphate). All factors and levels were included in all possible combinations in a randomized block design.

Sufficient seed of each species was planted to supply ten viable seeds per Number 10 can as indicated by germination tests. Actual stands were below expectations for foxtail, but quite uniform throughout. Each time the tallest plants reached a height of 12 inches, all species were clipped to a height of one inch, oven-dried and weighed. Two clippings were obtained before the test was terminated.

RESULTS AND DISCUSSION

Germination studies.

Results are shown in Table 1. Storage in ice or frozen sand resulted in a marked reduction in germination regardless of the length of

Table 1. Effect of various storage conditions on the germination of foxtail seed.

Storage medium	Temp. °F	Percent germination after storage, weeks				
		1	2	4	Averages	
Sand	10	15.8	10.0	13.8	13.2	26.6
	35	30.0	46.5	43.8	40.1	
Water	10	10.2	4.2	5.5	6.7	20.3
	35	46.0	33.5	22.2	33.9	
Dry	10	50.8	29.5	38.8	39.7	39.6
	35	52.2	28.5	37.8	39.5	
Average		34.2	25.4	27.0		

such storage. There was some indication that two weeks of storage under these conditions had more effect than a single week's storage, but this difference was not significant. Storage in ice had a more deleterious effect on germination than did storage in frozen sand. Storage at 35°F resulted in a slight reduction in germination, but this reduction did not become greater with time after two weeks (except possibly in water). In water, the trend of germination was downward, but the reduction with time was not quite significant at the 5 percent level. Dry storage at either temperature resulted in only slight reductions in germination, these possibly due to induction of dormancy rather than destruction of viability, since the trend in germination appeared to be upward after two weeks of such storage. Other studies showed that this seed had an average germination of about 50 percent before treatment. Of interest also is that the germination of this seed dropped to an average of 20 percent after storage in the laboratory for one year.

Such studies suggest that conditions found in the field during an average winter will result in a marked reduction in the germination of foxtail seed. This helps explain why most seedling establishment is in late summer and fall and why relatively few seedlings are found in the spring. Spring seeding in foxtail-infested fields should therefore result in much less competition from foxtail than would fall seeding.

Greenhouse water table studies.

The results of the 1956 studies are given in Figure 1. The relatively variable results of the 1955 test cast some doubt on its reliability, and the data are not given. However, the top growth was about the same at all water table depths while root growth tended to decrease as the water table was lowered.

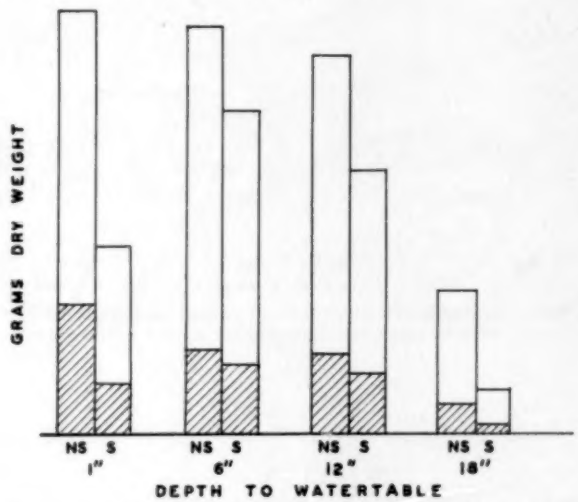

Figure 1. Effect of depth to water table on yield of roots (shaded) and shoots (unshaded) of foxtail barley when grown in the greenhouse on saline (S) and non-saline (NS) soils.

The 1956 studies repeated all treatments previously employed and in addition a new variable, soil salinity, was included. Analysis showed that both water table and salinity were significant factors in the growth of roots and shoots. For water table, the greatly reduced growth at the 18-inch level was the major factor in this difference; however, those plants growing in the saline soil at the one-inch water table level produced somewhat less dry weight than those in pots with six and twelve-inch levels. The plants at the eighteen-inch level had exhausted all available moisture from the areas penetrated by the roots and were dead or dying at harvest. Growth in the saline soil was uniformly less than in the non-saline

soil. The interaction between soil and water table was small and non-significant.

These studies indicate that foxtail barley is capable of near-normal growth even with a surface water table. In the seedling stage, however, its roots are not capable of penetrating moderate depths to a water table without additional moisture.

Field phytometers.

The effects of varying water tables on native pasture sods are shown in Figures 2 and 3. Despite a high degree of variability in

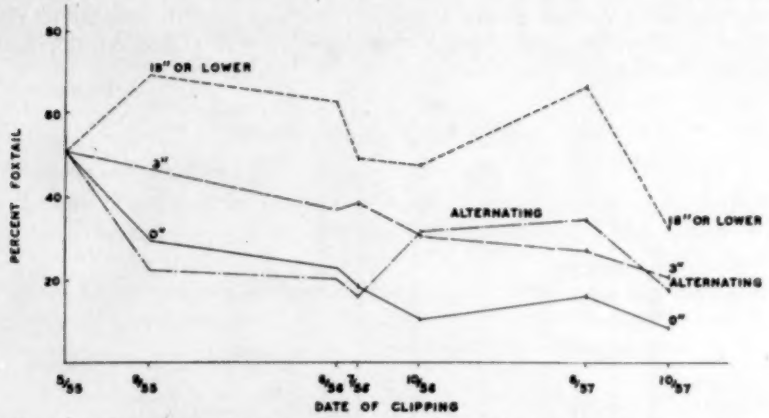

Figure 2. Effect on depth to water table on foxtail barley growing in competition with hydrophytic species in a native pasture sod.

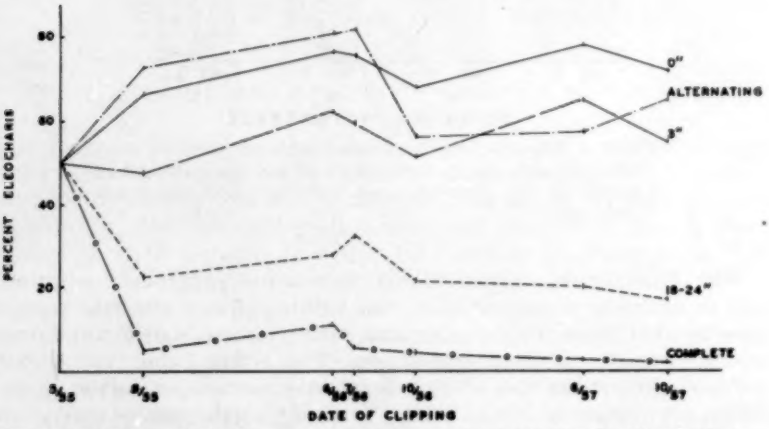

Figure 3. Effect of depth to water table on the hydrophytic *Eleocharis* sp. growing in competition with foxtail and other species in a native pasture sod.

these trials, certain water table effects soon became apparent. The first of these was the rapid decline in importance, but not disappear-

ance, of the hydrophytic spikesedge as soon as the water table was lowered more than a few inches below the surface. This decline was hastened by the lack of irrigation for a six-week period during the summer of 1955. Consequently, lessened competition allowed an increase in foxtail and invasion by annuals (Table 3). Some of these phytometers originally contained a trace of saltgrass (*Distichlis stricta*). In these phytometers, the saltgrass eventually increased (Table 2), and along with other perennial species, occupied a high

Table 2. Percent by weight of saltgrass at various dates in phytometers in which it occurred.

Water table	9/55	10/56	10/57
0 in	1.5	18.1	14.6
3 in	2.7	9.2	12.1
0–18 in	tr.	1.4	0.9
0–24 in	3.6	8.0	12.9
18 in	1.2	24.5	57.8
24 in	0.6	5.0	13.9
Completely drained	2.6	11.8	60.0

percentage of the area by the fall of 1957. A high water table in the spring was sufficient to maintain the spikesedge even though the water table declined later in the season (Figure 3).

Table 3. Percent by weight of annuals at various dates in field phytometers.

Water table	9/55	10/56	10/57
0 in	0	4.1	0
3 in	1.4	4.4	0
0–18 in	0.1	3.5	0
0–24 in	0.6	1.2	0
18 in	7.6	20.5	0
24 in	3.5	17.8	0
Completely drained	1.5	40.2	0

The effect of water table and salinity on seedling emergence in the seeded series of phytometers is shown in Figure 4. In general, emergence was suppressed at the three-inch water table. Likewise, fewer seedlings of foxtail barley emerged from the saline than from the non-saline soil, and no strawberry clover seedlings emerged from the saline soil. In contrast, tall wheatgrass and tall fescue emerged almost as well from the saline as from the non-saline soils. It would appear that foxtail barley has relatively poor emergence on the very sites on which it notoriously does best. It therefore must depend on a high seed population for a high establishment in these areas.

Growth after emergence followed a different pattern than did emergence. During the first year, before competition became a major factor, all species produced more dry weight on non-saline than on saline soils. During the second year, however, foxtail produced greater yields on the saline soils except at the three-inch

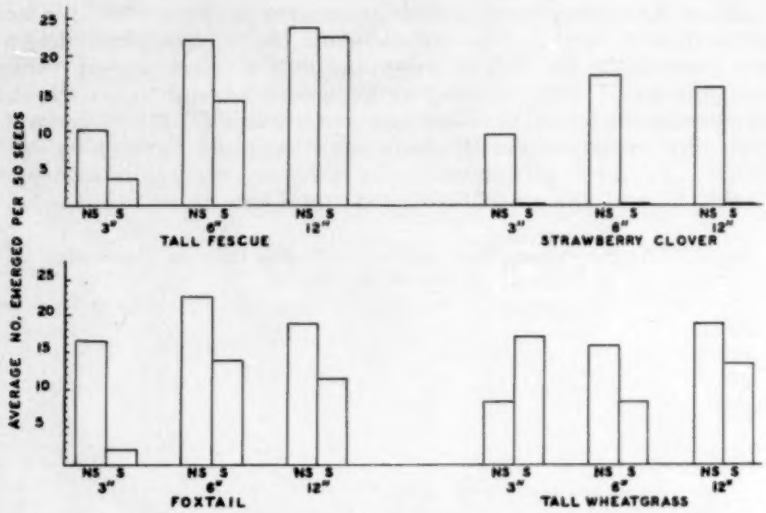

Figure 4. Effect of depth to water table (3″–12″) on emergence of foxtail barley and certain forage species when sown in saline (S) and non-saline (NS) soils.

water table level, whereas the forage species consistently yielded more on the non-saline soils regardless of water table (Figure 5). Also, the most forage yield and least foxtail was always obtained at the lowest water table level, i.e. 12 inches. This is in contrast to the performance of the hydrophytic species in the native sods discussed previously.

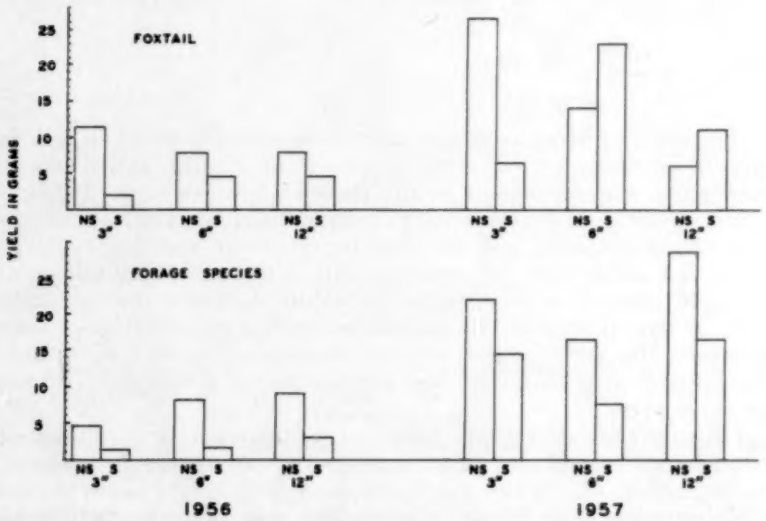

Figure 5. Effect of depth to water table on yield of foxtail barley and certain forage species grown in competition with each other on saline (S) and non-saline (NS) soils.

Fertility and salinity studies.

Poorer stands of foxtail were obtained on the saline soils when the nitrogen level was low. No other significant effects were found. Stands of tall fescue and tall wheatgrass were apparently not influenced by any of the variable factors in this study. This is similar to the results obtained in the field phytometers in which the same soils were used without addition of fertilizers.

The pots were harvested in December, 1955 and February, 1956. The data (Table 4) showed that nitrogen was the important nutrient

Table 4. Effect of fertilizer treatments on per plant yields of three grasses when grown in competition with each other on saline (S) and non-saline (NS) soils.

N added lb/A	P_2O_5 added lb/A	Salinity status	Foxtail grams	Tall fescue grams	Tall wheatgrass grams
100	0	NS	0.11	0.61	0.43
100	0	S	0.07	0.18	0.36
100	100	NS	0.21	0.49	0.33
100	100	S	0.14	0.22	0.41
0	0	NS	0.02	0.12	0.12
0	0	S	0.06	0.04	0.10
0	100	NS	0.04	0.22	0.20
0	100	S	0.06	0.05	0.09

limiting growth of the grasses in these soils. The addition of nitrogen fertilizer produced large and highly significant increases in dry matter regardless of any other factors involved. The level of salinity in the saline soils series caused markedly lower dry matter production by tall fescue. On the other hand, tall wheatgrass yielded about the same on either soil. Foxtail yield on the saline soil was reduced seriously and significantly only at the first harvest date. Among the three grasses, tall wheatgrass appears to be most tolerant of salinity, followed by foxtail, with tall fescue least tolerant. The results showed, however, that foxtail was quite sensitive to salinity during the early growth period. It eventually achieved a degree of tolerance almost equal to tall wheatgrass.

Foxtail was the only species that responded to phosphate applications in these tests, even though both soils were relatively low in phosphorus content. It is probable that plants known to remove large amounts of P from soils might be highly competitive with this species.

Although a number of the interactions involved were significant statistically, the results are difficult to interpret, especially since the plant responses show that the saline soil was more deficient in available nitrogen than the non-saline soil. Chemical tests indicated that both soils contained very low amounts (about 15 pounds per acre).

SUMMARY AND CONCLUSIONS

The germination studies suggest that the major source of seed for reinfestation by foxtail is from the current season's crop, and

that seed that overwinters in areas where the soil is frozen for any considerable time loses much of its viability. Foxtail seed loses viability fairly rapidly even under favorable storage conditions, and danger of prolonged reinfestation from dormant seed in the soil appears to be small. Since the major seedling crop is in the fall, spring seeding is indicated for areas in which foxtail is a serious pest.

Foxtail has a wide range of adaptation to varying water table conditions and its prevalence in otherwise favorable sites will depend largely on competition by other plants. With a surface water table, a hydrophyte such as the spikesedge offered sufficient competition to reduce foxtail to a minor component in the mixture, while under lower water table conditions, tall fescue and tall wheatgrass were able to reduce its prevalence. These results indicate that drainage without introduction of improved species on many native meadows and pastures will result in an increase of foxtail rather than a reduction, unless another mesophytic species is present to fill in the cover vacated by the hydrophyte.

Foxtail responded to nitrogen equally as well as tall fescue or tall wheatgrass in the early growth stages studied in this test. However, since adapted vigorous perennials appear to crowd out foxtail readily once they are well established, the possibility that nitrogen fertilization of perennial grasses may act as a control measure for foxtail cannot be ruled out.

As expected, foxtail is quite tolerant of saline soils and use of salt-tolerant competitors on highly saline soils is recommended. Tall wheatgrass appears to be even more tolerant of such conditions than foxtail, especially during the early stages of development.

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The Relative Toxicity of Three Boron Compounds and Sodium Chlorate Used as Soil Sterilants[1]

E. G. Scott[2]

Aslander (2) was the first worker to report on the use of sodium chlorate as a herbicide; and Crafts and Raynor (7) first reported on the use of borates as herbicides. They concluded that the herbicidal properties of any boron compound are related directly to the boron content of the compound. The fact that the borates tend to remain in the top layers of the soil while chlorates are easily leached, led them to propose that a mixture of the two would make an ideal soil sterilant.

Crafts (4), and Hurd-Karrer (8), noted that chlorate toxicity is inversely proportional to the level of nitrate in the soil. Aberg (1) reported that chlorate acts as a competitive inhibitor of the nitrate reductase system and he suggested that the effect of nitrate on chlorate toxicity is based on inhibition of this enzyme reaction. Crafts (4) reported that nutrient level has no apparent effect on borate toxicity but that soil texture influenced it considerably; he concluded that the borate was being fixed by the clay fraction of the soil. As a result of this work, it was possible to recommend a formulation of a mixture of chlorate and borate to contain "chlorate through its maximum effectiveness"–and enough borate to complete the destruction (Crafts and Cleary, 6). In general the commercial preparations have combined sodium chlorate ($NaClO_3$) and sodium tetraborate (containing 33% B_2O_3) in the ratio 1 to 3 or 1 to 5.

Stone and Stahler (12) tested the toxicity of sodium chlorate, sodium polyborate, and borate-chlorate mixtures, on a number of plant species grown in solution culture in Vermiculite. They found that with beans, alfalfa, sweetclover, and zinnias, the borate was as effective as the borate-chlorate mixtures, and more effective than the chlorate alone. With oats they found no significant difference in the toxicities of the individual chemicals and mixtures. However, Crafts (4) had already noted that boron toxicity in a solution culture is considerably greater than in a soil culture, and therefore the results of Stone and Stahler may not hold in soil. Stone and Stahler are conservative in the conclusions they draw, stating that 1 part $NaClO_3$ equals 1 part B_2O_3 under their conditions. Crafts and Cleary (6) had previously found that 3 parts borax (approximately 33% B_2O_3) or 1 part sodium chlorate reduced growth to the 10 percent level.

This paper presents solution and soil culture experiments to determine the relative effectiveness of borate and chlorate under both these culture conditions.

[1]This research, conducted at Davis, California, was supported by grants from the Chipman Chemical Co., Bound Brook, New Jersey.

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MATERIALS AND METHODS

Soil experiments.

Four soils, Columbia fine sandy loam, Yolo clay loam, Fresno sandy loam, and Stockton adobe clay, were each treated with four toxicants; sodium chlorate, sodium tetraborate, sodium metaborate, and sodium pentaborate, at 80, 160, 240, 320, 400, and 480 ppm B_2O_3 or ClO_3 in air dry soil. The test plants were oats, barley, and sunflower. The method of treatment was as follows: after pulverizing and passing through a ¼-inch sieve, 500 grams of the air-dry soil was weighed out into a number 2 can, the chemical was added in 50 ml of aqueous solution, the soil brought to field capacity, and seeded, ten seeds per can for barley and oats, four for sunflower. The cultures were kept at field capacity by watering daily, and after thirty days the tops were harvested and their fresh weights determined. The plant material was placed on top of the soil which was then left for thirty days to dry. Then the soil was pulverized and replaced in the can with the material from the previous harvest in the bottom of the can so that nothing was lost from the culture. The soil was brought to field capacity and the cycle of seeding and harvesting repeated. Thus it is possible to obtain data on the residual activity of the herbicides without loss by leaching and the removal of plant materials.

Pertinent data for the soils and herbicides used are presented in Tables 1 and 2.

Table 1. Field capacities, cation exchange capacities and reactions of soils (pH).

Soil	Field capac.	C.E.C. mill. eq. per 100 gm soil	pH values			
			Untreated	Tetraborate	Pentaborate	Metaborate
Columbia fine sandy loam	18%	10.7	6.4	7.5	6.7	8.1
Fresno sandy loam	21%	14.5	7.6	8.3	7.7	8.8
Yolo clay loam	30%	18.9	7.0	7.7	7.2	8.1
Stockton adobe clay	32%	21.9	6.7	7.0	6.8	7.5

Table 2. Composition and solubilities of boron compounds.

Borates	Formulae	$\%B_2O_3$	$\%Na_2O$	% solub. at 20 C.
Sodium tetraborate	$Na_2B_4O_7.10H_2O$	35.5	16.2	4.9
Sodium pentaborate	$Na_2B_{10}O_{16}.10H_2O$	59.0	10.2	15.4
Sodium metaborate	$Na_2B_2O_4.8H_2O$	25.2	22.5	42.4

Results.

The results of the first run of each experiment are shown in graphic form, where the mean yield of three replications expressed as percent of the control mean is plotted against the respective concentration. In order to present the results of the four runs as simply as possible a figure termed "total effect" was found by deriving the mean yield for each concentration series and expressing this figure as the percent of the control yield from this soil and run.

Kanota oats.

From Figure 1 it is obvious that the findings of Crafts and Cleary (6) and Stone and Stahler (12) have been substantiated. There was

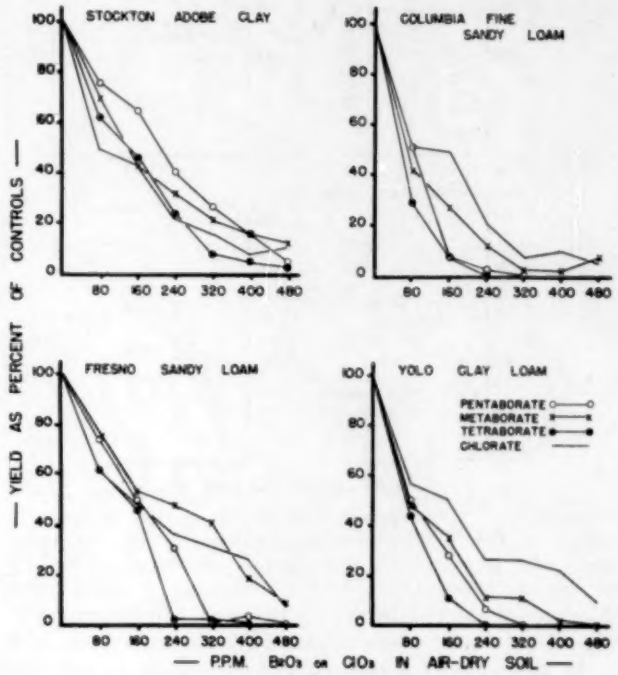

Figure 1. Run 1: comparison of the toxicity of the four herbicides to Kanota oats grown in four different soil types (mean yield of three replicates).

no overall significant difference in the toxicity of chlorates and borates to Kanota oats, except in Yolo clay loam, where all three borates were significantly more toxic than chlorate. Throughout the four soils the toxicity of borate was not simply a factor of B_2O_3 concentration, for the three borates show significant differences when present in the same concentration (based on B_2O_3). The total effect or residual curve (Figure 2) shows that while chlorate experiences a steady decrease in toxicity with successive croppings the decrease in that of borate seems to be staggered. For instance, the yield in run 2 from the metaborate in Stockton adobe clay is greater than the yield of run 3. These differences in the residual activity of borates and chlorates are much more pronounced in the barley experiment and will be discussed at greater length there.

Sunflower.

The striking feature of these results is the toxicity of the sodium chlorate to sunflower (Figure 3); for there was no growth from any

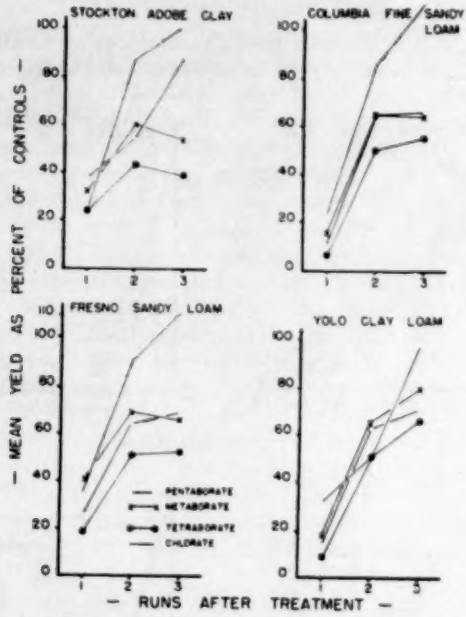

Figure 2. Kanota oats "Total effects". Comparison of the percent toxicity, over three runs, of the four herbicides to Kanota oats grown in the four soil types.

of the chlorate treated cultures in this run. In contrast, borate is lethal to sunflower only when applied at concentrations of 160 ppm or above. As was noted for the oat experiment, a steady decrease in chlorate toxicity with time is evident (Figure 4). Here also there is a staggered decrease in the borate toxicity and by run 4 there is no significance to the difference in toxicities of sodium tetraborate and sodium chlorate. The differences in toxicity of the three borates, which have already been noted as being present in run 1, are maintained throughout the four runs. It is of interest in this connection that while the borate toxicity curves of each soil show some specific characteristics, there are general tendencies within the four, e.g. in three of the soils the lowest borate toxicity is in run 2.

Barley.

From Figures 5 and 6 it would seem that while barley reacts to borate as does Kanota oats its reaction to chlorate parallels that of sunflower. The 80 ppm cultures were omitted in this series and in all four soils there was no growth in any of the chlorate treated cultures at 160 ppm (Figure 5). Borate was lethal only when presented at concentrations above 240 ppm. The differences in toxicity among the three borates is again noticeable. In all four soils there is a continuous decrease in chlorate toxicity from one run to the next (Figure 6). The overall borate reaction is also one of decreasing

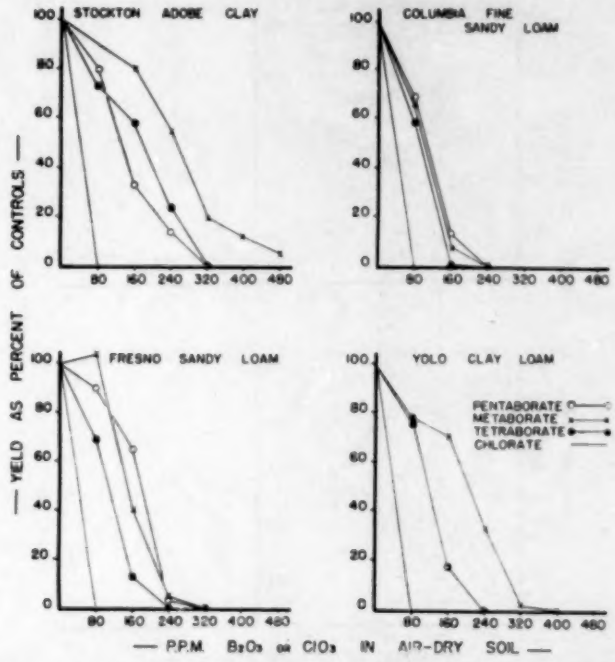

Figure 3. Run 1: comparison of the percent toxicity of the four herbicides to sunflower grown in four soil types (mean yield of three replicates).

activity with time—although having the earlier noted "staggered" effect—but the decrease is at a considerably faster rate than that of chlorate. The factor causing these differences in borate toxicity from one run to the next may be environment: where control growth was greatest toxicity was at a minimum and vice versa. It is of interest to note that for all four soils the "total boron" curves are very much alike, indicating that factors other than soil texture may limit boron toxicity.

Solution culture experiments.

The same four herbicides were used in solution culture. The barley was grown in sterilized sand for seven days then transferred to quart Mason jars (10 seedlings per jar) containing a modified Shive's solution. After two weeks the seedlings were transferred to pure solutions of the herbicidal chemicals; after 44 hours they were returned to the culture media. One month after seeding the plants were harvested and the fresh weights of the tops determined.

The second solution culture was designed to test the effect of the herbicides when presented continuously to the plants as components of the culture solution. To prevent precipitation of salts, boric acid was used in place of the sodium borates, all of which

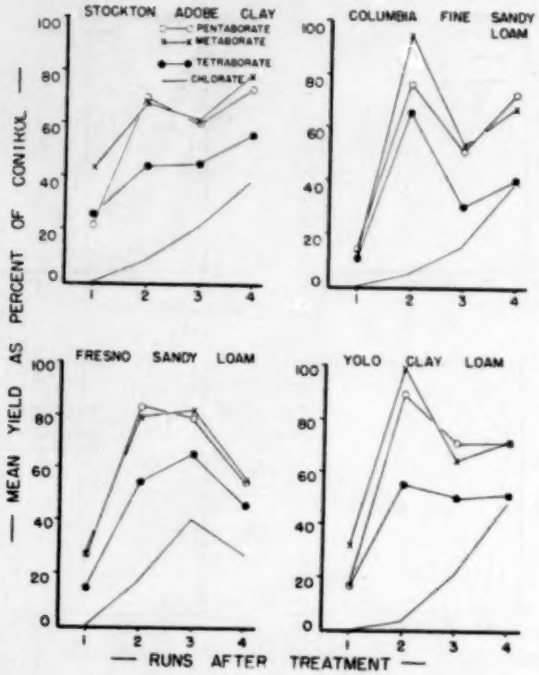

Figure 4. Sunflower "Total effects". Comparison of the percent toxicity, over four runs, of the four herbicides to sunflower grown in the four soil types.

caused salt precipitation. As before, the barley plants were germinated in sand and transferred to Shive's solution at the end of seven days. After one week, borate (B_2O_3) and sodium chlorate were added to the cultures. Two weeks later the plants were harvested and weighed.

The modified Shive's solution used in these experiments contained: $Ca(NO_3)_2$—.0039M; $MgSO_4$—.00225M; KH_2PO_4—.00224M; microelements as in Hoagland's solution; pH was 5.5.

Results.

The two solution culture experiments were carried out in order to test some ideas arising from the soils work. Since the conditions are similar to those of Stone and Stahler (1954), this work also allowed some duplication of their experiments. The results are presented graphically in Figures 7 and 8.

The first solution experiment used the four sterilant chemicals. The barley plants, growing in a modified Shive's solution were placed in the sterilant solution for 44 hours then returned to the Shive's for a further week. The toxicity of the chlorate was considerably greater than that of the borate, as was the case in the

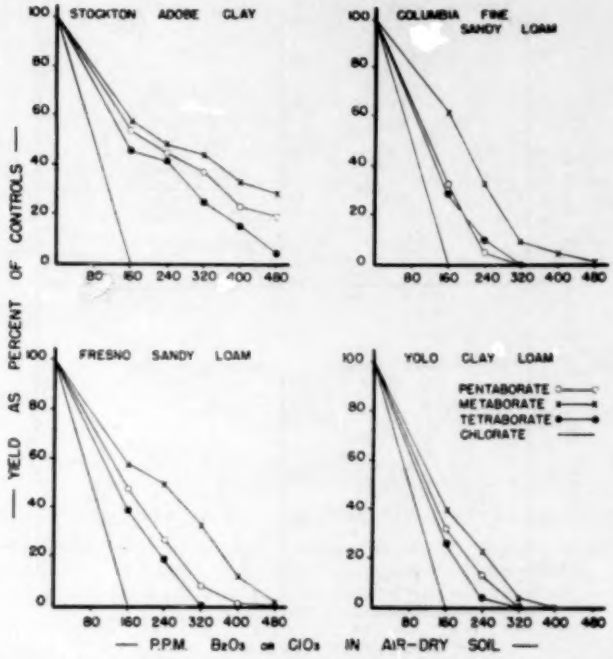

Figure 5. Run 1: comparison of the percent toxicity of the four herbicides to barley grown in four soil types (mean yield of three replicates).

soils work. The relatively high value for metaborate toxicity at concentrations above 900 ppm may be due to a pH effect and the other two borates may give a more realistic picture of borate toxicity. Figure 7 shows that after a short-time exposure to borate at concentrations as high as 1500 ppm in solution, plant growth was reduced to 70% of the control while chlorate at a similar concentration reduced it to 10% of the control figure.

The second solution experiment tested the relative effect of borate and chlorate to barley and oats when these chemicals are present in the culture solution. The plants were grown for one week in normal Shive's solution, then the solution was changed to one of Shive's plus the respective sterilant. After two weeks in this solution the plants were harvested. Figure 8 shows that in solution culture as in soils the reaction of these two plants is different. At 450 ppm and above the oats show a greater reaction to borate than to chlorate, while for barley the reverse is true. However, it is very apparent that the real specificity lies in the response of these two species to chlorate, for the differences in the response to chlorate are considerably greater than those to borates. In fact, at 450 ppm chlorate has the lowest toxicity value when applied to oats and the highest value when applied to barley.

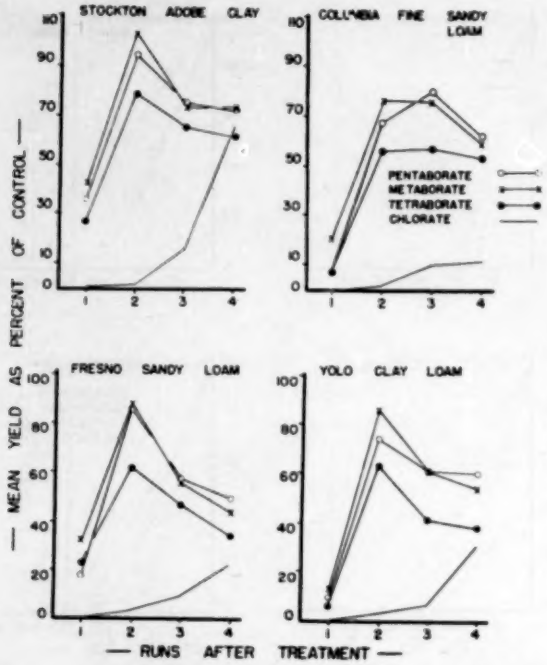

Figure 6. Barley in solution culture. Comparison of the relative percent toxicity of four herbicides to barley after 44 hours exposure of the plants to solutions of the respective pure chemicals (mean yield of three replicates).

Respiration experiments.

Oxygen uptake of oat seedlings was determined in the Warburg respirometer at 30°C. The seeds were sterilized with Ceresan and plated onto sterile petri dishes containing 5 number one filter papers which had previously been wet with 5 ml of the respective meta- or tetraborate solution. At the end of periods of 30, 50, and 70 hours after seeding the seeds were removed to 15 ml Warburg flasks (six seeds per flask). Two ml of the respective germinating solution was placed in the flask along with the seeds. Following a thirty minute equilibration period oxygen uptake was measured over a period of ninety minutes. Then the fresh and dry weights of the seeds were determined.

Results.

Because the toxicities shown by the three borates in soils differed from those found by Stone and Stahler (1954) these respiration experiments were designed to find the relation of molecular structure of borates to toxicity. As shown in Figure 9, tetraborate reduced the oxygen uptake below that of the control for all three concentrations used (Figure 9a). This inhibition of oxygen uptake

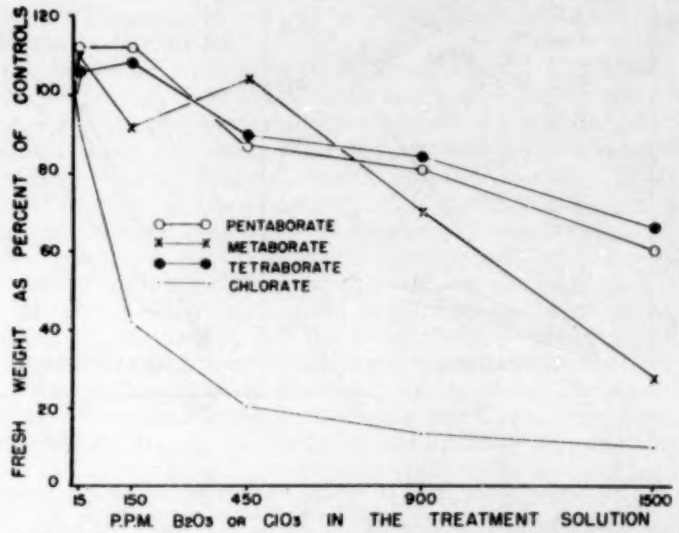

Figure 7. Barley in solution culture. Comparison of the relative percent toxicity of four herbicides to barley after 44 hours exposure of the plants to solutions of the respective pure chemicals (mean yield of three replicates).

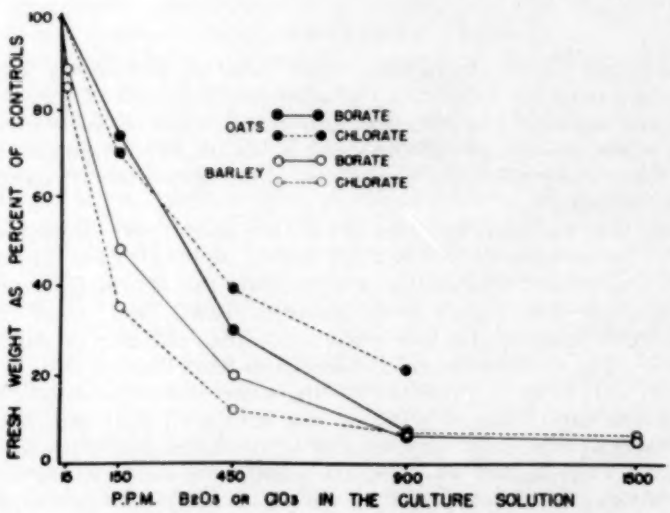

Figure 8. The relative toxicity of borate and chlorate on oats and barley grown in solution culture (mean of three replicates).

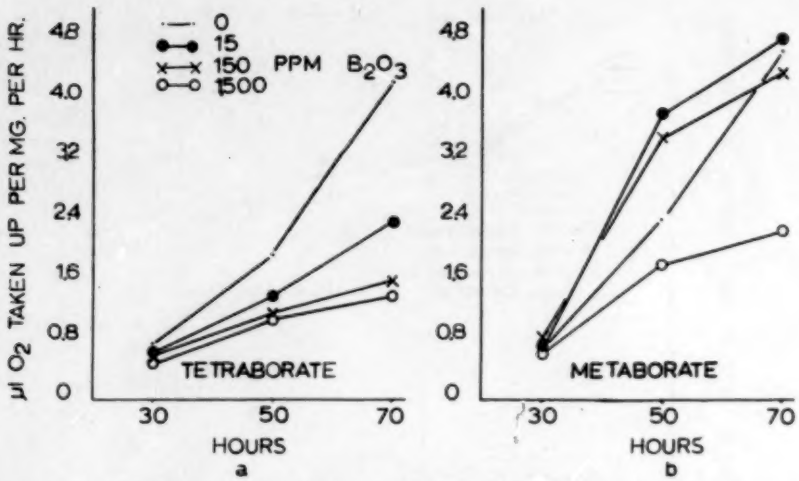

Figure 9. Comparison of the effect of sodium tetraborate and sodium metaborate on the respiration of germinating Kanota oat seedlings.

increased with increase in the length of exposure to tetraborate. After thirty hours of treatment metaborate stimulated oxygen uptake, and after fifty hours only at the 1500 ppm level was the oxygen uptake lower than that of the control. The two borates appeared to affect the respiration of oat seedlings differently. Tetraborate was inhibitory after short periods of exposure, but metaborate only became inhibitory after extended exposure times and only at high concentrations.

Discussion

Crafts and Cleary (6) discussed the value of greenhouse experiments as a basis for field recommendations. It should be noted that where the toxicity of a chemical is dependent on its accumulation in the plant, as seems to be the case for borate, it will appear much more toxic under the ideal conditions of the greenhouse than under field conditions.

From the experiments described two points are immediately obvious in relation to the relative merits of borates and chlorates as soil sterilants. First, on the species used the action of borate is not highly specific; borate toxicity curves (run 1, and "total effect" of all three species) did not show any great differences within a soil type. The variance of this observation from those made in field trials is clear; in these experiments the borate was distributed evenly throughout the root zone while in the field with deep and shallow rooted species this is not the case. For all three test plants the toxicity of borate is affected by soil type, a phenomenon noted in the earlier work of Crafts, and borne out by statistical analysis. However, from the "total effect" curves we note that the differences due to soil type are almost masked by other environmental factors which lend

an overall similarity to the curves in various soils and even to all of the curves within the barley and oat series. Thus, with but two exceptions (barley in Columbia soil, and sunflower in Fresno soil) the lowest borate "total effect" is in run 2. Apparently the toxicity of borates in soil is governed by environmental conditions that limit transpiration, and by other processes controlling ion accumulation; soil texture is also involved. Second, chlorate toxicity, in striking contrast to that of borate, shows high specificity; in the plants which are susceptible to chlorate (barley and sunflower) fairly low concentrations are highly effective as compared with any of the three borates. This specificity of chlorate may be explained on the basis of differences in the nitrate reductase systems of the various species. From the curves showing total effects, it may be seen that environmental conditions which favor growth seem to have very little effect on residual chlorate toxicity; the latter decreases with subsequent runs and shows considerable differences from one soil to another (cf. Crafts, (4), on the effect of nitrate on chlorate toxicity).

The second solution culture experiment bears out the idea that plant response to chlorate is specific whereas that to borate may be less so. The evidence is that the response of both test plants to boric acid is intermediate, whereas the response to chlorate is maximum with barley and minimum with oats.

Data from the first solution culture appears to substantiate the idea that borate toxicity is limited by factors affecting accumulation. After 44 hours exposure to borate the barley shows very little response, whereas the chlorate treatment for a similar period is almost as effective as when chlorate is presented over the entire growing period (cf. barley-chlorate curves in Figures 7 and 8). On the other hand when borate is presented over the whole growing period it is almost as effective as chlorate (Figure 8), thus suggesting that borate toxicity is primarily dependent on accumulation of borate ion.

The inherent differences in toxicity among the three borates in soil cultures are not easily explainable on the basis of any of their known properties, especially since there is little or no difference in the solution cultures. The excessive toxicity of metaborate in solution may result from its high pH and may not be a true reflection of the borate effect. One possible explanation is the difference in the ratio of the various ions present in the solutions of the three salts, which could result in the preferential absorption of one ion by the plants or in a greater precipitation of borate from solution in one case. The concept of a single borate ion being effective could explain the differences in respiration of oat seeds germinated in metaborate and tetraborate. Since metaborate is less rapid in decreasing respiration it can be assumed that the toxic ion is in a lower concentration in its solution than in the solution of tetraborate.

From the foregoing experiments it seems that the reaction to borate of the species tested is similar; the most toxic of the three borates in soils was sodium tetraborate. On the other hand, the

reaction to chlorate is specific; some species such as barley are very sensitive.

With a series of borate: chlorate mixtures tested under uniform conditions it was found that increasing the borate: chlorate ratio decreased the effectiveness on barley, while for oats, such mixtures had apparently equal toxicity no matter what the ratio was. From this latter observation we might conclude that one part B_2O_3 equals one part ClO_3. However, it is obvious from the soil experiments with barley and sunflower, and from the solution culture work that such a generalization has little validity.

From this work and from field plots put out by the University Extension Service, it seems that as a general soil sterilant, mixtures of sodium chlorate and sodium borate give maximum effectiveness when mixed in a borate: chlorate ratio greater than four. Apparently one should apply a mixture at a rate which will provide chlorate at its optimum effectiveness while containing enough borate to complete the sterilization process.

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Histoautoradiographic Studies of Herbicidal Translocation[1]

M. A. Radwan, C. R. Stocking, and H. B. Currier[2]

An understanding of the physiological action of various herbicides is based in part upon a knowledge of (1) the exact path of movement of the substance in the plant, (2) the rapidity of transfer from one tissue to another, and (3) the relative proportion of the total conductive tissue that is effective in transfer under any given set of conditions. Although the intercellular distribution of radioactive isotopes in both plant and animal tissues has been studied by the use of histoautoradiography (6), only one brief paper (8) describes the use of this method with plant growth regulators.

A histoautoradiograph is obtained by bringing a thin tissue section (1 to 25 μ) containing a radioisotope into close contact with a photographic emulsion which is exposed and later developed. Microscopic examination is then made to correlate the pattern of developed emulsion grains with the tissues of the section.

Two of the major problems encountered in this procedure are the loss of labeled substance from the tissue and diffusion from the initial location to other locations within the tissue during fixation and dehydration. These artifacts can be minimized by (1) the use of precipitants that react with the herbicide to form insoluble and immovable deposits, together with fixatives that do not dissolve the compound being studied (15, 17); (2) by the application of a freeze-drying technique of the Altmann-Gerch type (9, 10, 12); or (3) by a combination of these two methods. The present paper deals with the evaluation of these techniques in the study of the intercellular movement of labeled 2,4-dichlorophenoxyacetic acid (2,4-D) and 3-amino-1,2,4-triazole (amitrole).

Materials and Methods

Broad bean (*Vicia faba* L.) was the test plant. The plants were treated with amitrole-C^{14}, labeled in carbon 5 position, with an activity of 1.3 mc/mM; and with 2,4-D-C^{14}, carboxyl-labeled, having an activity of 6.03 mc/mM.

In one procedure, chemicals were applied to one leaflet of a fully-expanded basal leaf when the plants, grown in pots under greenhouse conditions, were 15 days old and about 5 inches high. The herbicides were dissolved in 50% ethanol containing 0.1 per cent of either X-77 or Vatsol OT as surfactant and then applied uniformly over the surface of the leaflets. The plants were kept in an illuminated constant temperature cabinet until harvested.

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In order to study upward translocation, roots of seven-day-old plants, grown in aerated half-strength Hoagland's solution, were dipped into test tubes containing aqueous solutions of the tagged herbicides. At the end of the treatment period, the roots were washed with distilled water and blotted between filter paper.

Survey autoradiography. To obtain a general picture of the distribution of the herbicides in the plant before preparing material for histoautoradiographic study, autoradiographs of whole plants were made. In the downward translocation experiments each plant received 0.5 μc of either 2,4-D*[3] or amitrole* in 10 μl of the alcohol solution. After 6 hours in the illuminated constant temperature cabinet the plants were harvested, freeze-dried, and autoradiographed according to the method of Pallas and Crafts (16). Photographs of the autoradiographs and of the freeze-dried plants are shown in figures 1A, 1B, 2A, and 2B.

For the upward translocation studies, aqueous solutions containing 2.7 μc/ml of 2,4-D* (sodium salt) or 4.0 μc/ml of amitrole* were used. The treatment period was 6 hours and the harvested plants were freeze-dried and autoradiographed (figures 3A, 3B, 4A, and 4B).

Histoautoradiography. Each leaf-treated plant received 13.5 μc of amitrole* or 13.1 μc of 2,4-D* in 25 μl of solution. After 6 hours the plants were harvested. The root-treated plants were grown 20 hours in solutions containing 4.0 μc/ml of 2,4-D* (sodium salt) or 6.0 μc/ml of amitrole*. Three methods of preparing the samples were tested.

1. *Intracellular precipitation of the herbicides.* Preliminary trials indicated that mercuric salts precipitated both amitrole and 2,4-D. An attempt was made to use this precipitation reaction to prevent diffusion of the herbicides during the preparation of the section. Five-millimeter segments (stem, petiole, or root) of the treated plants were vacuum infiltrated with a dilute solution of mercuric nitrate and then either placed in fixative or frozen and dried as outlined in subsequent sections. Although this treatment was found to reduce leaching of the herbicides during liquid dehydration of the tissue samples, $Hg(NO_3)_2$ was not used in the histoautoradiographic study because it reacts with the photographic emulsion.
2. *Liquid fixation.* Amitrole*-treated material was fixed in formalin-acetic-alcohol (FAA) solution while 2,4-D* material was fixed either with dry ice or Zirkle's fixative. The material was then dehydrated with liquid dehydration, embedded in paraffin, and sectioned.
3. *Freeze drying.* Immediately upon harvesting, segments of treated plants were frozen in isopentane previously cooled to about −160°C with liquid nitrogen. The samples were then freeze-dried in vacuo at −40°C (9) in a Virtis freeze-drying apparatus, embedded in paraffin, and cut at 15 μ with a rotary microtome.

[3]The asterisk denotes radioactivity.

Development of histoautoradiographs. Paraffin ribbons were expanded on water at 42°C, transferred to water at 18 to 20°C and mounted in the dark on Eastman Nuclear Track Plates NTB-2. Less than 1 minute was required for these operations. The plates previously had been soaked for 5 minutes in water at 20°C to insure good adhesion between the emulsion and the sections. No adhesives were used. With the sections in place, the plates were dried in the dark for 12 hours over calcium sulfate. The plates were then packed in a light-tight box containing a desiccant and stored in a refrigerator for 10 to 60 days.

At the end of the exposure period, the paraffin was removed with xylene. The plates were transferred through an alcohol series to water, developed in full strength Kodak D-19 developer at 20°C, rinsed in water, fixed in Kodak acid fixer, and washed in running water.

The developed plates were stained with Harris' haemotoxylin for 1 minute, blued in alkaline water, counterstained for 1 minute with eosin (7), and mounted in Harleco resin.

All radioactivity counting data were obtained by use of a Tracerlab windowless flow counter.

RESULTS AND DISCUSSION

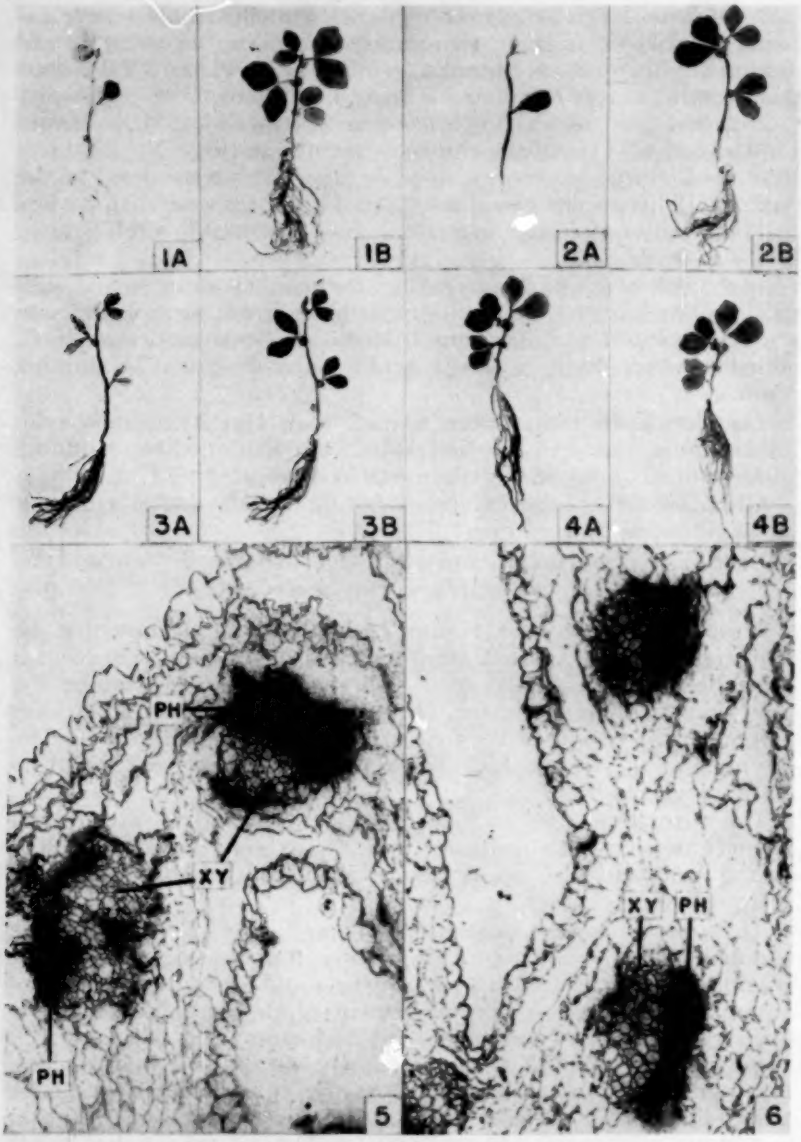
Survey autoradiography. Figures 1A, 1B, 2A, and 2B show that the radioactivity from applied amitrole* and 2,4-D* was translocated from the treated leaflets to most of the rest of the plant under the conditions of the experiment. However, the highest activities were present in the petiole of the treated leaf and in the stem just below the node of the treated leaf. These regions were selected for histoautoradiographic studies.

The autoradiographs in Figures 3A, 3B, 4A, and 4B as expected (4) indicate that both amitrole* and 2,4-D* were taken up rapidly by the roots and in 6 hours were well distributed throughout the entire plant.

An important aspect in studies utilizing labeled herbicides is the metabolic fate of the herbicide during the translocation period. Obviously if the herbicide is rapidly metabolized in the plant, histoautoradiographs may reflect movement of the decomposition products rather than of the unchanged herbicide. It is, however, well known (11, 13) that 2,4-D is only slowly metabolized in the plant. Hay and Thimann (11) recovered, as the unmetabolized herbicide after 6 hours, 94% of the 2,4-D applied to bean plants, and Jaworski and Butts (13) report the recovery of 90% of the applied 2,4-D after 24 hours. Amitrole appears to be even more stable than 2,4-D in plants.[4]

It is thus evident that histoautoradiographs of plants treated with amitrole* or 2,4-D* 6 hours prior to harvest should show the position of the herbicides rather than of metabolic products.

[4] O. A. Leonard, personal communication.



Figures 1 to 6. In Figures 1 to 4 autoradiographs are indicated as A and photographs of treated, freeze-dried *Vicia faba* plants as B. *Figure 1 (A and B).* Amitrole* applied to upper surface of most mature leaflet for 6 hrs. *Figure 2 (A and B).* 2,4-D* applied to upper surface of most mature leaflet for 6 hrs. *Figure 3 (A and B).* Roots dipped 6 hrs. in a 2,4-D* (sodium salt) solution. *Figure 4 (A and B).* Roots dipped 6 hrs. in amitrole* solution. *Figure 5.* Portion of petiole X-section and autoradiograph. Amitrole* applied to upper surface of most mature leaflet of plant for 6 hrs. Phloem ph, xylem xy. x125. *Figure 6.* Portion of petiole X-section and autoradiograph. 2,4-D* applied to upper surface of most mature leaflet of plant for 6 hrs. Phloem ph, xylem xy. x125.

Tissue preparation. In order to determine the effect of liquid dehydration on the loss of activity from sections, the processing liquids were concentrated under reduced pressure and assayed for radioactivity. The results permit the following findings:

1. Direct liquid dehydration resulted in a significant loss of activity from tissue. Most of the activity lost was found in the first few solutions having a relatively low ethanol concentration.

2. There was less loss of amitrole* to the dehydrating solutions than of 2,4-D*. About half of the amitrole* escaped; practically all of the 2,4-D* was lost. This could be due either to differences in solubility or to a greater adsorption of amitrole* than 2,4-D* on cell surfaces.

3. Increasing the number of solutions used in fixation and dehydration resulted in increased loss of activity, i.e., use of Zirkle's solution caused more leaching than dry ice fixation.

Loss of activity from sections. Five-millimeter segments of petiole or stem were embedded in paraffin and cut at 15 μ. The activity of individual sections representing the different treatments was determined. Four undeparaffined sections were used for each determination and results were compared with the activity lost during precipitation and dehydration. The data, presented in Table 1, indicate that:

Table 1. The effect of different methods of preparation on the activity lost from and retained by individual sections.

Method of preparation	Activity lost—per cent of total	Activity retained—cpm/15μ section
Amitrole*		
$Hg(NO_3)_2$, FAA, liq. dehyd.	12.9	1.0–12.0
Direct liq. dehyd.	47.8	0.0
$Hg(NO_3)_2$+freeze drying	0.?	1.5–2.0
Direct freeze drying — Stem	0.0	2.0–2.5
Direct freeze drying — Petiole	0.0	2.2–3.0
2,4-D*		
$Hg(NO_3)_2$+dry ice+liq. dehyd.	46.4	0.5–3.0
$Hg(NO_3)_2$+Zirkle's+liq. dehyd	60.8	0.2–1.5
Direct liq. dehyd.	97.5	0.0
$Hg(NO_3)_2$+freeze drying	18.1	5.2–5.5
Direct freeze drying — Stem	0.0	6.0–8.0
Direct freeze drying — Petiole	0.0	18.0–22.0

1. The highest activity occurred in sections taken from freeze-dried segments, the lowest in sections from liquid-dehydrated segments.

2. Although Hg $(NO_3)_2$ infiltration decreased the loss of activity from tissue, it apparently changed the original distribution of herbicide. In one instance, sections from the ends of the 5-mm segments showed an activity 12 times that contained by middle sections. This technique was not used further.

3. The 2,4-D* petiole sections contained approximately 4 times as much activity as stem sections. Contrastingly, there was no comparable difference shown in amitrole* sections. This seems to indi-

cate that amitrole* moves more rapidly and becomes more evenly distributed than 2,4-D*, in the 6-hour treatment.

4. Although approximately the same amount of activity was applied, the 2,4-D* petiole and stem sections always contained more activity than the amitrole* sections. Differences in penetration behavior and in specific activity (2,4-D* 5 to 6 times greater than amitrole*) helps to explain this result, and 2,4-D* is known to be adsorbed more tightly to cell surfaces than amitrole* (5).

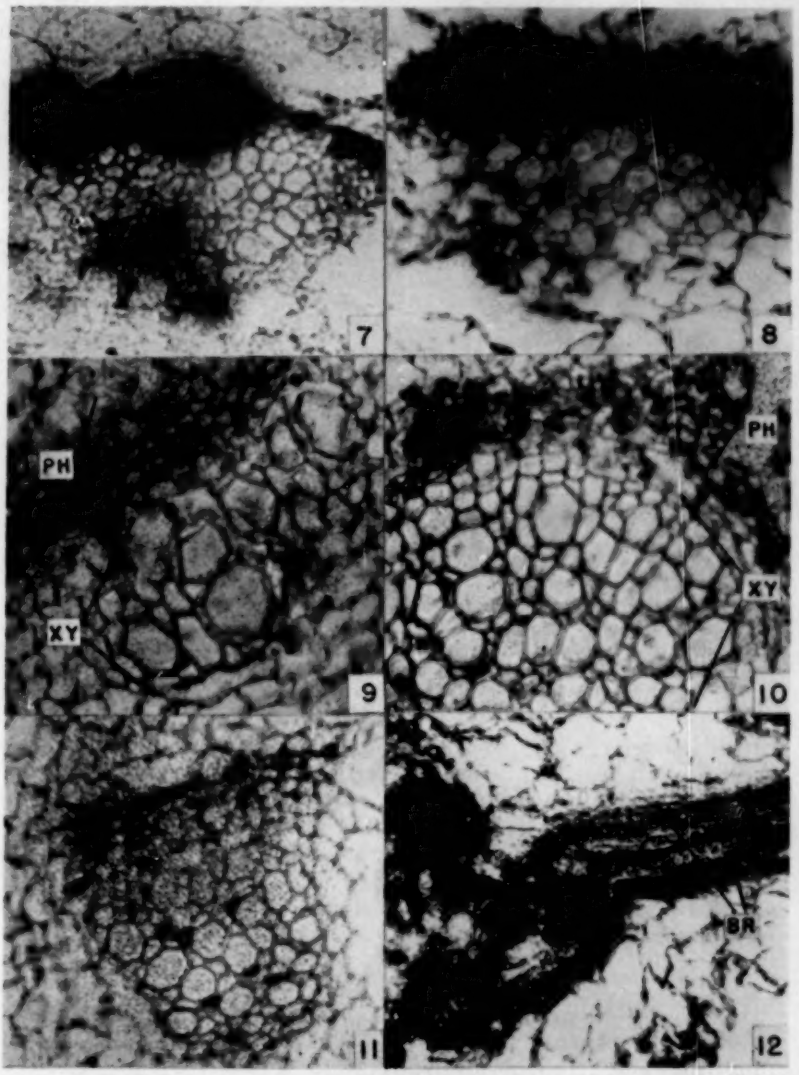
All further tests were conducted using the freeze-drying technique, without precipitation, followed by imbedding the tissue in paraffin.

In the technique finally adopted the paraffin ribbons came in contact with water during the brief period in which they were expanded and mounted on the moist nuclear track plates. The possibility of diffusional artifacts occurring at this time exists. However, care was used at this step to reduce the time to a minimum. Although the complete elimination of the possibility of any diffusional artifacts is desirable, the results in Figures 5 to 14 indicate that the method employed was successful in producing histoautoradiographs in which the location of high concentrations of radioactivity are clearly shown in certain tissues and little or no activity is present in others. Diffusion of radioactivity away from such areas of high activity during the preparatory procedure would reduce the intensity of radioactivity in these tissues and cause a general activity over the entire slide.

Downward translocation. The autoradiographs show that not all vascular bundles were equally effective in transport. In addition, within one cross-section, the phloem of different bundles showed different amounts of activity. Further, only part of the phloem apparently participated in translocation. In all instances there was activity in the phloem, although sometimes a small amount, above the general background, was present in the protoxylem (Figures 5,6). That the herbicide moved first in the phloem and then began to diffuse into the xylem is indicated by the relative amounts present in each (Figure 7), and by the fact that no activity was ever found in xylem alone, but often occurred almost solely in the phloem (Figure 8).

These results are in agreement with the prevailing view (4) that 2,4-D, amitrole and other systemic foliar-applied herbicides move out of the leaves via the phloem. In general, the results are also in line with Biddulph's (2, 3) observations on movement of S^{35}, P^{32}, and C^{14} in the red kidney bean plant. The presence of the herbicide in the xylem is not unexpected, although it is not clear why protoxylem, rather than metaxylem, should be involved.

Examination of 2,4-D* and amitrole* stem sections with their autoradiographs revealved the same distribution of activity as did petiole sections. However, activity in the phloem was less because of the greater distance from point of application, and the resulting dilution effect. Many bundles appeared to exhibit activity throughout the xylem (Figures 9, 10). As the distance increased basipetally from the point of application the activity in the xylem increased



Figures 7–12. Distribution of radioactivity in petiole, stem, and root of *Vicia faba* plants. Phloem ph, xylem xy. *Figure 7.* Enlarged view of one of the petiole bundles from a plant that was treated with 2,4-D* on upper surface of most mature leaflet for 6 hrs. x260. *Figure 8.* Enlargement of one of the petiole bundles from a plant that was treated with 2,4-D* on upper surface of most mature leaflet for 6 hrs. x310. *Figure 9.* X-section of stem vascular bundle with autoradiograph. Amitole* applied to upper surface of most mature leaflet of plant. Section removed just below node of treated leaf. x280. *Figure 10.* X-section of a stem vascular bundle with autoradiograph. 2,4-D* applied to upper surface of most mature leaflet of plant. Section removed just below node of treated leaf. x280. *Figure 11.* X-section of a stem vascular bundle with audioradiograph. 2,4-D* applied to upper surface of most mature leaflet of plant. Section removed 2 inches below node of treated leaf. x200. *Figure 12.* Portion of root X-section with autoradiograph, from plant root-treated 20 hrs. with 2,4-D* (sodium salt). Branch root indicated by br. x230.

(Figure 11). This may be due to both direct lateral transfer from the phloem (2, 3) and re-translocated activity (from the roots).

Upward translocation. Figure 12 shows the movement of 2,4-D* into the main root through a branch root. Once absorbed, the herbicide moved across to the xylem of the main root (Figure 13) where upward transport began. Under the influence of transpiration pull, the herbicide moved rapidly in the transpiration stream. Most

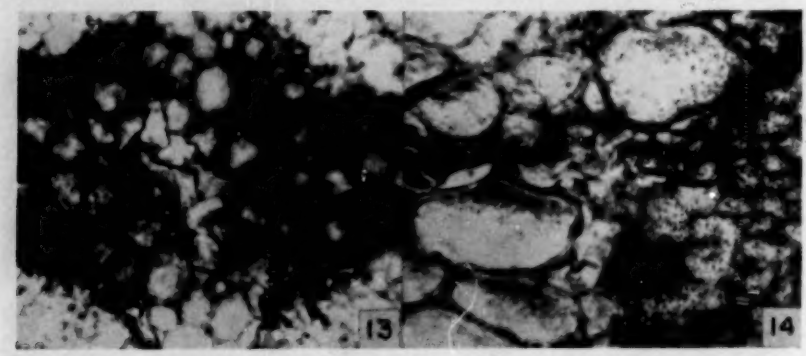


Figure 13. Portion of root X-section with autoradiograph, from plant root-treated 20 hrs. with 2,4-D* (sodium salt). Vessels show high activity. x200. *Figure 14.* Portion of stem X-section with autoradiograph, from plant root-treated with amitrole*. Section removed 2 inches above cotyledons. Note activity in large vessels at left, also in phloem at right. x500.

of this movement occurred in the xylem vessels although there was some activity in the phloem, especially at higher levels (Figure 14). This probably indicates a direct transfer from xylem to phloem cells. Such a cross transfer of mineral ions was demonstrated many years ago (18). It is also possible that the herbicide after reaching the cotyledons is re-exported upward in the phloem (1). Moreover, a downward retranslocation from the leaves via the phloem is not improbable (14).

SUMMARY

Histoautoradiographic methods for determining the cellular distribution of two C^{14}-labeled herbicides, 3-amino-1,2,4-triazole (amitrole) and 2,4-dichlorophenoxyacetic acid (2,4-D), are described. *Vicia faba* was the test plant. The herbicides were applied to leaves and roots. Histoautoradiographs of freeze-dried petioles and stems of leaf-treated plants always showed activity in the phloem. In addition, the xylem frequently showed some activity. As the distance from point of application (blade) increased, the activity in the phloem decreased and that in the xylem increased.

Root and hypocotyl sections of root-treated plants showed most activity in the xylem but always a certain amount in the phloem.

The results suggest lateral transfer between xylem and phloem, for both leaf- and root-absorbed tracers.

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Relative Toxicity of Extracts from Vegetative Organs of Quackgrass to Alfalfa[1]

J. H. Ohman and Thor Kommedahl[2]

Introduction

Hot water extracts of quackgrass (*Agropyron repens* (L.) Beauv.) rhizomes and leaves have been reported by Kommedahl et al. (2) and Le Tourneau et al. (3) to inhibit seed germination and growth of various crop plants. Experiments were performed to determine in which organs the toxic material is located, whether it is the same substance in all organs, and to compare toxin production in two clonal lines of quackgrass. In addition, experiments were performed to determine whether soil in which quackgrass had been growing was toxic and to determine if toxic material is present in young seedlings.

Materials and Methods

For the experiments involving clonal material, two lines of quackgrass were propagated from rhizomes in the greenhouse and the plants were harvested after four months. Leaves, stems, roots, and rhizomes were separated and dried at 90°C for 24 hours immediately prior to extraction.

Seedlings were harvested two and four weeks after emergence. In order to test only the effect of extracts of the seedling and not the grain, the adhering remains of the grains were removed and the seedlings were dried at 90°C for 24 hours immediately prior to extraction.

Soil for extraction was taken from one lot originally, then divided into three portions: one portion was used to grow quackgrass for one year, the second was used to grow Canada thistle (*Cirsium arvense* (L.) Scop.) for one year, and the third was stored in a soil bin indoors for one year. All three portions were autoclaved immediately prior to extraction. The soil which had been used to grow Canada thistle was included to compare with quackgrass the effects of another perennial weed. All macroscopically visible plant material (roots, rhizomes, etc.) was removed from the soil before extraction.

Extractions of plant materials were done in a Soxhlet extractor using distilled water as the solvent. The cycling rate of the extractor was adjusted to 4 per hour and the extraction was stopped at 98 hours. Volumes of extracts were adjusted to equal a 2.5 per cent solution based on the original oven-dry weight of the material extracted. Extractions of soil were made in the same manner except that volumes were adjusted to equal a 10 per cent solution.

Toxicity of the various extracts was determined by germinating

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alfalfa (*Medicago sativa* L. var. Ranger) seeds in deep Petri plates containing three filter papers (9 cm in diameter) and 10 ml of extract or distilled water. Plates and papers were autoclaved before extracts were added and seeds were surface disinfested by dipping them in a solution of 1:2000 Merthiolate (sodium ethyl mercury thiosulfate) in 50 per cent ethanol for three minutes. Twenty-five alfalfa seeds were germinated in each plate. Plates were incubated at 26°C for 72 hours, then germination counts were made and seedling length was measured. Seedling length was measured from the root tip to the cotyledonary node. The data given are representative of several tests.

The data were subjected to an analysis of variance and the Student-Newman Kuels multiple range test (1).

RESULTS

Extracts of material from clonal lines reduced seedling lengths of alfalfa 63 to 82 per cent as compared to the checks, whether the extracts were obtained from roots, stems, rhizomes, or leaves. Statistical analyses showed that these reductions were not significantly different from each other at the 1 per cent level. The principal difference observed between extracts from various organs or between extracts from the two clones was in the effect on germination. In both clones, extracts from leaves reduced germination much more than extracts from other organs. Results are summarized in Table 1. Extracts from seedlings two and four weeks after emergence

Table 1. Effect on seedling length and germination of Ranger alfalfa of aqueous extracts of various quackgrass organs from two clones and from seedlings two and four weeks after emergence.

Extract	Seedling length mm	Statistical significance[a]		Per cent germination	Statistical significance[a]	
		.05	.01		.05	.01
Clone 7[b]						
H_2O check	35.5	a	a	86	a	a
Root	13.0	b	b	73	b	ab
Stem	10.2	bc	b	66	b	b
Rhizome	6.3	c	b	78	ab	a
Leaf	6.4	c	b	42	c	c
Clone 8[b]						
H_2O check	37.5	a	a	82	a	a
Root	11.7	ab	b	74	a	a
Stem	8.7	bc	b	73	a	a
Rhizome	7.4	c	b	77	a	a
Leaf	8.1	c	b	58	b	b
Seedlings[c]						
H_2O check	38.4	a	a	86	a	a
2-week-old seedlings	9.1	b	b	53	b	b
4-week-old seedlings	8.5	b	b	48	b	b

[a]Any two means within a column not having letters in common are significantly different at the indicated levels.
[b]Data based on 200 seeds per extract.
[c]Data based on 100 seeds per extract.

produced approximately the same toxic effects as did extracts from leaves of older plants.

Extracts of soil did not differ significantly in their effect on germination, but did differ in their effect on seedling length. Extracts of soil which had been used to grow quackgrass reduced seedling length more than did extracts from other soils. Extracts from Canada thistle soil and stored soil did not differ significantly in their effects on either germination or seedling length (Table 2).

Table 2. Effect on seedling length and germination of Ranger alfalfa of aqueous extracts of soil which had been either stored, or had contained Canada thistle or quackgrass[a].

Extract	Seedling length	Statistical significance[b]		Per cent germination	Statistical significance[b]	
	mm	.05	.01		.05	.01
H_2O check	48.2	a	a	80	a	a
Stored soil	26.1	b	b	66	b	b
Canada thistle soil	25.7	b	b	64	b	b
Quackgrass soil	17.7	c	c	62	b	b

[a]Data based on 100 seeds per extract.
[b]Any two means within a column not having letters in common are significantly different at the indicated levels.

To determine whether chemical differences existed between extracts of leaves and rhizomes, 50 ml each of leaf and rhizome extracts were placed on separate 40×500 mm columns containing a mixture of 15 gm of activated carbon (Darco G-60) and 30 gm of Celite 537, a filter aid. All toxicity was removed from rhizome extracts after passage through the columns, while considerable toxicity still remained in the effluent of leaf extracts (Table 3).

Table 3. Effect of activated carbon, Darco G-60, on toxicity of leaf and rhizome extracts of quackgrass using seedling length and germination of Ranger alfalfa as a bioassay[a].

Extract	Passage through Darco G-60	Seedling length mm	Statistical significance[b]		Per cent germination	Statistical significance[b]	
			.05	.01		.05	.01
H_2O check	no	30.7	a	a	80	ab	ab
Rhizome	no	14.7	c	b	79	ab	ab
Rhizome	yes	30.7	a	a	86	a	a
Leaf	no	9.8	c	c	63	c	b
Leaf	yes	25.2	b	a	70	bc	ab

[a]Data based on 100 seeds per extract.
[b]Any two means within a column not having letters in common are significantly different at the indicated levels.

DISCUSSION

All vegetative parts of quackgrass apparently can produce substances as early as two weeks after emergence that are toxic to alfalfa

seedlings. Moreover such substances may accumulate in soil and remain there for some time, as shown by testing extracts from quackgrass soil. In previous work (2) seedlings of wheat and oats fared poorly when grown in quackgrass soil. Extracts from Canada thistle soil, and even from soil without plants, also proved to be toxic to alfalfa, but to a lesser degree. If it can be subsequently established that substances from quackgrass accumulate in soil for even weeks at a time, the ecological role of quackgrass in interspecific competition assumes greater importance.

Extracts from quackgrass leaves differ from extracts of rhizomes primarily in their effect on germination of alfalfa. While equal concentrations of the raw extracts inhibit seedling length of alfalfa by the same amount, leaf extracts are much more inhibitory to germination than rhizome extracts. These results, coupled with the fact that passage through activated carbon removed all toxicity from extracts of rhizomes but only part of the toxicity from extracts of leaves, suggests the possibility that both leaves and rhizomes contain a substance, X, which is removed by the carbon, but that the leaves contain an additional substance, Y, which is not removed. The substance Y would appear to have a slight effect on reducing length of seedlings, but a comparatively greater effect on lowering the percent of germination. The concentration of this additional material in the leaves appears to be the principal difference between the two clonal lines tested, as briefly reported previously (4).

SUMMARY

Hot water extracts of roots, stems, rhizomes, and leaves reduced seedling lengths of alfalfa by approximately 65 to 80 per cent as compared to checks in each of the two clones tested. Reduction in germination of alfalfa was approximately 5 to 15 per cent for extracts of roots, stems, and rhizomes, but leaf extracts from one clone reduced germination by 30 per cent and from another by 50 per cent. Extracts of quackgrass seedlings two and four weeks after emergence exhibited about the same toxicity as leaf extracts of older plants.

Extracts from soil in which quackgrass had been growing were more deleterious to seedling growth of alfalfa than were extracts obtained from soil in which Canada thistle had been growing or where no plants had been growing, but, extracts made from all soils were somewhat toxic to alfalfa seedlings, whether plants were growing in them or not.

Extracts from leaves or rhizomes of quackgrass, when passed through activated carbon, were found to be different from each other in that all of the toxicity was removed from rhizome extracts while only part of the toxicity was removed from leaf extracts, as measured by a bioassay with alfalfa.

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Simazine for Controlling Weeds in Fruit Tree and Grape Plantings[1]

R. P. Larsen and S. K. Ries[2]

Practical and economical weed control measures are a necessary part of tree fruit and grape production. Weeds and grasses are serious competitors of fruit plants for moisture and nutrients; they provide cover for destructive mice, and interfere with harvest of the crop.

Mechanical methods of weed control are labor consuming, expensive and sometimes injurious to the roots and trunks of the fruit plants. The fruit grower looks to chemical control methods as the ultimate answer to his weed control problems.

In recent years, monuron, diuron, and dalapon have shown promise as herbicides for fruit trees and grapes, (1,2,3,4,8). Dalapon is used for the control of grasses in apple and pear orchards (9), and diuron is used in grape vineyards (8).

Simazine has, likewise, shown considerable promise with a number of ornamental genera, including *Malus* (5,6,7). Ries et al. (7) found it to be the most promising of several materials tried because of its excellent weed killing properties, long residual action and the number of tolerant nursery species.

The purpose of these experiments was to evaluate 2-chloro-4,6-bis(ethylamino)-*s*-triazine (simazine) as a weed killer for fruit trees and grapes.

Experimental Procedure

Tree fruits.

Three separate experiments were carried out on various kinds, varieties and ages of fruit trees. Simazine was applied as a ground spray in about 30 gallons of water per acre at a pressure of 25 psi. Single tree treatments were replicated three or more times. Treatments included hoed and unhoed trees. The hoeing was done one day before the simazine applications. The treatments were conducted at the Michigan State University Horticulture Farm, East Lansing, on a Hillsdale sandy loam to loam soil.

I. *Young fruit trees.* Simazine at 4 and 8 lb/A was sprayed over a 16 sq. ft. area around young Jonathan and Delicious apple trees in May 1958 and 1959. The trees were 1-year-old at the time of initial application.

Redhaven and Richhaven peach trees and Montmorency cherry trees of the same age received rates of 2 and 4 lb/A in 1959.

II. *Bearing apple trees.* Simazine at 2,4,8, and 16 pounds per acre was applied as a ground spray to 7-year-old apple trees during 2 years, 1958 and 1959. Granular simazine, as a dry treatment, was

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applied at 8 and 16 pounds per acre. Each treatment covered 144 sq. ft. around each tree.

III. *Bearing peach, cherry, and pear trees.* In 1958 only, simazine sprays at 4,8, and 16 pounds per acre were applied to 144 sq. ft. areas around fully mature trees of peach, sour cherry and pear.

The weed population in the above tests consisted primarily of dandelion (*Taraxacum officinale*), lambsquarters (*Chenopodium album*), pigweed (*Amaranthus retroflexus*), alfalfa (*Medicago sativa*), timothy (*Phleum pratense*), downy brome (*Bromus tectorum*), and crabgrass (*Digitaria sanguinalis*).

Observations for possible injury to the trees were made at intervals during each growing season. Weed control ratings were made in late July of each year using a scale of 1.0 for no weed control, 6.0 for commercially practical control, and 9.0 for weed eradication. Trunk diameter measurements of the young trees in Experiment I were obtained in October of 1959 to determine if the treatments had any effect on relative growth rates of the trees.

Grapes.

Weed control treatments were made in a vineyard of 4-year-old Concord grapes during May 1958 and 1959 at the Michigan State University Horticulture Farm, East Lansing and at the Sodus Horticultural Experiment Station, Sodus. The treatments at East Lansing included simazine (4 and 8 lb/A) and diuron (2 lb/A) on hoed plots, and simazine (8 lb/A) on unhoed plots. Treatments at Sodus were on previously hoed plots and included simazine (2,4 and 8 lb/A) and diuron (2 lb/A). Diuron is used commercially in Michigan vineyards and was included for a comparison.

The treatments consisted of 3 vines each, replicated 3 times. Sprays were applied with the same equipment as for the tree fruit studies. They were applied in a 3-foot band directly under the trellis. The soil at East Lansing is a Hillsdale sandy loam and the soil at Sodus is a Kalamazoo sandy loam.

The primary weeds at East Lansing were quackgrass (*Agropyron repens*), plus annual weeds as listed for tree fruits. At Sodus, the primary weed was quackgrass with lesser amount of barnyard grass (*Echinochloa crusgalli*), purslane (*Portulaca oleracea*), and the other annual weeds previously listed.

Visual observations were made throughout each growing season to determine effects of the treatments on vine growth. Weed control ratings using a scale of 1.0 for no control, 6.0 for commercial control, and 9.0 for weed eradication and yield records were obtained in September of each year. Percent soluble solids of fruit from each plot at the Sodus experiment were obtained at harvest time using a Zeiss hand refractometer. The soluble solids value was obtained from the juice of 4 apical berries from 25 basal clusters.

RESULTS

Tree fruits.

There were no visible symptoms of injury to any fruit trees except where simazine was applied at 16 lb/A. Suckers at or below the

ground level on the bearing apple trees treated at this rate had a typical interveinal chlorosis of the leaves; however, no injury was present on the main branches. The mature peach and cherry trees treated at 16 lb/A in 1958 showed no injury until midseason the following year at which time practically all the leaves had a slight chlorosis.

Trunk diameters of the treated apple and peach trees of Experiment I were significantly larger than those of the untreated checks, Table 1. It was also clearly apparent that the treated trees had larger top growth with larger leaves and longer terminals than the untreated trees. Even though the trees were grown on better than average soil for fruit trees and with high fertility levels, it was evident that the weed competition resulted in some dwarfing of the untreated apple and peach trees.

There were no significant differences in the trunk diameters or determinable visual differences in top growth of the cherry trees between any treatments. Gilbert (2) also found no difference between herbicide treatments in terminal growth or trunk diameters of young sour cherry trees.

Weed control of these experiments was very promising at all levels of application. However, only 8 and 16 lb/A resulted in commercially acceptable control.

Table 1. Trunk diameters of young apple, cherry and peach trees treated with simazine in May, 1958 and 1959 and measured in October, 1959.

Treatment	Rate lb/A	Culture	Diameter (mm)		
			Apple[a]	Cherry[b]	Peach[c]
None	–	Hoed once	26.2	39.5	47.3
Simazine	4	Hoed once	32.2	45.0	53.0
Simazine	8	Hoed once	33.0	38.5	55.6
Simazine	8	Not hoed	32.0	43.5	52.3
LSD at .05			3.1	N.S.	4.7
LSD at .01			4.3	N.S.	N.S.

[a]Averages of 5 trees.
[b]Averages of 2 trees.
[c]Averages of 3 trees.

Table 2 shows the weed control ratings for the young trees. Alfalfa and dandelions were not adequately controlled at the lower rates, whereas 8 lb/A gave a very satisfactory control of both, (Figure 1). There was no difference in weed growth between the hoed and unhoed trees at the time of rating even though a 6 to 8 inch weed growth had occurred when the treatments were applied.

Table 3 shows the weed control ratings of the treatments applied to bearing apple trees. Treatments with 8 or 16 lb/A of simazine had commercially acceptable control. When comparing similar rates, there were no significant differences between hoed and unhoed trees or between wettable and granular simazine.

Table 2. Average weed control from two years applications of simazine on 2-year-old apples, cherries, and peaches.

Treatment	Rate lb/A	Culture	Ratings[a]		
			Apples[b]	Stone fruits[c]	
			1958+1959	1958	1959
None	–	After hoeing	1.0	1.0	1.4
Simazine	2	After hoeing	—	4.4	—
Simazine	4	After hoeing	5.3	5.6	5.0
Simazine	8	After hoeing	7.3	—	6.4
Simazine	4	Not hoed	—	5.6	—
Simazine	8	Not hoed	7.2	—	6.4
LSD at 5%			.4	.4	1.3
LSD at 1%			.5	.6	1.8
Coefficient of variation			8%	5%	8%

[a]Weed control rating scale: 1.0 = no control, 6.0 = commercially acceptable control, 9.0 = eradication of weeds.

[b]Averages of 5 trees— 3 Jonathans and 2 Delicious for both years. There was no difference between years.

[c]Averages of 5 trees—2 Montmorency cherry, 1 Richhaven peach, and 2 Redhaven peach.

Figure 1. Weed control around a two year old apple tree from simazine at 8 lb/A.

Table 3. Average weed control ratings on bearing apple trees treated 2 years.

Simazine treatments	Rate lb/A	Culture	Weed control ratings[a]
None	—	Hoed	1.0
Wettable	2	Hoed	4.7
Wettable	4	Hoed	5.3
Wettable	8	Hoed	7.8
Wettable	4	Not hoed	4.7
Wettable	8	Not hoed	7.0
Wettable	16	Not hoed	8.3
Granular	8	Not hoed	5.7
Granular	16	Not hoed	7.5
LSD at 5%			1.7
LSD at 1%			2.3
Coefficient of variation			25%

[a]There was no difference between 1958 and 1959 ratings. Weed control rating scale: 1.0 = no control, 6.0 = commercially acceptable control, 9.0 = eradication of weeds.

Eight and 16 lb/A of simazine applied only in May, 1958 to unhoed trees of peach, sour cherry, and pear resulted in excellent weed control both in 1958 and 1959 (Table 4).

Table 4. Average weed control ratings for two years on bearing sour cherry, peach and pear trees from applications made only in 1958.

Treatments	Rate lb/A	Culture	Weed control ratings[a]
None	—	Not hoed	1.0
Simazine	4	Not hoed	4.1
Simazine	8	Not hoed	7.9
Simazine	16	Not hoed	8.8
LSD at 5%			0.8
LSD at 1%			1.1
Coefficient of variation			15%

[a]There was no difference in ratings between 1958 and 1959. Weed control rating scale: 1.0 = no control, 6.0 = commercially acceptable control, 9.0 = eradication of weeds.

Grapes.

There was no evidence, either by yield or observation, of injury to grape vines at East Lansing or Sodus from the use of simazine or diuron.

Simazine at 8 pounds per acre applied at East Lansing resulted in commercially acceptable weed control on both hoed and unhoed areas (Table 5). Simazine at 4 lb/A or diuron at 2 lb/A did not satisfactorily control either the annual weeds or quackgrass. The use of simazine had no influence on yield (Table 5).

All treatments of simazine and diuron resulted in commercially acceptable control of annual weeds at Sodus (Table 6). Simazine at 4 and 8 pounds per acre and diuron at 2 pounds per acre resulted in excellent quackgrass control.

Table 5. Average weed control ratings and yields from treatments for two years on Concord grapes at East Lansing, Michigan.

Treatments	Rate lb/A	Culture	Weed control ratings[a]	Yield tons/A
None	–	Hoed	1.2	4.2
Simazine	4	Hoed	4.8	3.6
Simazine	8	Hoed	6.0	3.9
Simazine	8	Not hoed	7.5	3.9
Diuron	2	Hoed	4.5	4.0
LSD at 5%			1.3	N.S.
LSD at 1%			1.8	N.S.
Coefficient of variation			23%	19%

[a]There was no difference in ratings between 1958 and 1959. Weed control rating scale: 1.0 = no control, 6.0 = commercially acceptable control, 9.0 = eradication of weeds.

The difference in weed control at East Lansing and Sodus was attributed primarily to the differences in soil types. The soil in the East Lansing vineyard was a good fruit soil ranging from Hillsdale sandy loam to loam, whereas the Sodus soil was a light sandy loam. Since many vineyards in Michigan are grown on light sandy soil, the results obtained at Sodus were probably more applicable to the general vineyard conditions of the State.

The influence of weed competition on vine production is shown in Table 6 which presents a direct correlation between degree of weed control and yield of the vines. All herbicide treatments resulted in significantly higher yields than the untreated checks. There were no differences in soluble solids content of the harvested fruit.

Table 6. Average weed control, yield, and soluble solids of Concord grapes from two years treatment at Sodus, Michigan.

Treatment	Rate lb/A	Weed control ratings[a]		Yield tons/acre	Soluble solids per cent[b]
		Annuals	Quackgrass		
None	–	1.0	1.7	4.3*	15.5
Simazine	2	6.7	5.3	4.7	15.7
Simazine	4	7.8	7.6	5.5	16.5
Simazine	8	7.5	7.8	5.5	16.0
Diuron	2	7.7	7.5	5.3	16.2
LSD at 5%		2.1	2.4	N.S.	N.S.
LSD at 1%		2.9	3.3	N.S.	N.S.
Coefficient of variation		29%	33%	20%	4%

[a]There was no difference between 1958 and 1959 ratings. Weed control rating scale: 1.0 = no control, 6.0 = commercially acceptable control, 9.0 = eradication of weeds.
[b]One year's results only.
*F. value for comparison of no treatment with all treatments significant at the 5% level.

SUMMARY

Simazine was used at 2 to 16 lb/A around various ages and varieties of apple, sour cherry, peach, and pear trees. Rates of 8 pounds per acre or less resulted in no visible injury to any trees. Simazine at 16 pounds per acre applied in 1958 resulted in foliage injury of bearing peach and sour cherry trees the following year. Growth of young apple and peach trees in simazine treatments was greater

than trees in untreated checks. Commercially acceptable control of weeds was obtained under bearing and non-bearing trees with 8 or 16 lb/A of simazine. Weeds were not adequately controlled at rates lower than 8 pounds.

Simazine at 2 to 8 lb/A and diuron at 2 lb/A was applied under 4-year-old Concord grape vines at East Lansing and Sodus, Michigan. Simazine at 8 lb/A resulted in excellent control of weeds and grasses on the sandy loam soil at East Lansing. Other treatments did not provide adequate weed control. There was no evidence of injury to the vines from any treatment. All treatments of simazine and diuron provided acceptable or nearly acceptable control of weeds and quackgrass on the sandy loam at Sodus, Michigan. Yields of treated vines were significantly higher than untreated check and there was no evidence of foliar injury from the herbicide treatments.

These studies indicate that simazine can be used to control annual weeds and grasses under fruit trees and grapes without causing injury to the plants. However, several years of use and observation are probably needed before commercial recommendations can be made. Rates of 4 to 8 lb/A appeared most satisfactory for light soils ranging from loam to sandy loam.

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Where We Stand With Witchweed

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WITCHWEED (*Striga asiatica*) was first collected and identified in the United States during the late summer of 1956. This parasite attacks the roots of plants primarily in the family Gramineae. In the United States it appears to be a potential threat to the corn and grain sorghum crops. The seed of this annual germinates under very exacting conditions and can attach itself to a growing root tip of a host plant. Infestations build up, and spread is by seed which are produced in abundance. Beginning infestations may cause a few stunted crop plants while older infestations may cover several acres or entire fields and completely kill the host plants before they can produce a crop.

The USDA Plant Pest Control Division, working cooperatively with state regulatory agencies and land-grant colleges, assumed responsibility for regulatory and survey activities. Intensive surveys in North and South Carolina uncovered 1739 infested properties in 1957 and an additional 2188 in 1958. During the summer growing season of 1959, 2167 more such properties were surveyed, making a total of 6094 known infestations in the two states. An infested property is considered as a farm, or similar area, known to have witchweed on it. The total known land infested or subject to immediate infestation is about 116,000 acres. When witchweed is discovered in a field, although the infested area is only a few hundred square feet, the entire field unit is considered as infested acreage. The general area of infestation includes 15 counties in southeastern North Carolina and seven adjoining counties in northeastern South Carolina. About 75% of the infested properties are located in four North Carolina counties and one South Carolina county. In addition to these two states, intensive to light survey work has been done in several other states, with all reports negative.

A major effort in 1957 was to learn to identify the weed, to establish a quarantine and to define the general area of infestation. In 1958 a control program utilizing the "catch crop" system was undertaken on about 1,000 acres. A "catch crop" involves planting a host, such as corn, to encourage the germination of witchweed seed and then plowing in both the corn and witchweed plants before new witchweed seeds are formed. A second "catch crop" of corn, grain sorghum or millet is handled in the same manner and is followed in the fall with a cover crop of oats. The farmer, under a cooperative agreement, furnishes the service, seed and fertilizer. He is supervised by the USDA Plant Pest Control Division and is reimbursed to do the work. No crop is harvested following the use

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of a "catch crop". This reduces regulatory work and contributes to preventing the spread of witchweed seed.

The "catch crop" program was used on 15,887 acres in 1959. The field program was expanded to include spraying 2,4–D, to which witchweed is susceptible. This spraying program used from one-half to one pound 2,4–D per acre as an amine salt in directed applications. It covered about 50,000 acres of cultivated cropland and almost 7,500 acres of non-cropland for an average of about five applications. To accomplish the spraying job, it was necessary to secure equipment, which included 35 high-clearance sprayers, 30 "Jeep" mounted boom sprayers, 40 ¾-ton labor carrying pick-up trucks, 31 ½-ton labor and water carrying trucks, 80 trailer type 300- to 450-gallon tanks, 35 "Jeep" supply vehicles and 650 knapsack sprayers. At the peak of activity, 648 seasonal employees were being used and all of these men had to be trained. As a result of repeated applications, including each new "find", as discovered, approximately 250,000 acres of land were sprayed.

The general accomplishment of the entire program has been to define the area of infestation, to protect non-infested land by quarantine and to prevent many witchweed plants from producing seeds. The accomplishments of the 1959 spraying program include preventing practically all witchweed seed production but overall results can only be determined by what happens in the years to come. There is little doubt that the population of witchweed seed in the soil of infested land is lower than it would have been without the program. A similar intensive program is anticipated in 1960 and within a few years a noticeable reduction in the number of witchweed plants and crop damage from witchweed is expected. For 1959, the immediate purpose of preventing witchweed from producing seed was accomplished.

A remarkable feature of the 1959 spraying program is that a quarter million acres of witchweed infested land in the midst of cotton, tobacco and vegetable crops were sprayed with about a quarter million pounds of 2,4–D as an amine salt by previously inexperienced personnel and not a single accident or incident of serious crop damage occurred. This stands as a tribute to thorough preparation and conscientious supervision by the Plant Pest Control Division personnel. The continuation of such an overall effective program can be expected to greatly minimize the potential threat from witchweed.

Control of Horsenettle (*Solanum carolinense*) in Pastures[1]

W. B. Albert[2]

Horsenettle (*Solanum carolinense*) is a drought-resistant, deep-rooted perennial plant that propagates itself from rhizomes and seed, both of which are produced in abundance. In pastures propagation from seed is probably of minor importance as compared to the steady increase in infestation occurring from rhizome growth.

Mechanical methods of horsenettle control have not been satisfactory and chemical methods have been only partially effective. Bradbury and Aldrich[3] reported that 4 foliar applications at 5-day intervals of various phenoxy compounds, chlorobenzoic acids and amitrole resulted in some topkill but did not reduce infestation in the following season. Practically complete control of horsenettle followed October applications of 32 pounds per acre of phenoxy materials with lesser amounts significantly reducing infestation the following season.

Preliminary experiments at Clemson showed that foliar applications of ½ to 2 pounds per acre of 2,4–dichlorophenoxyacetic acid (2,4–D) and 2,4,5–trichlorophenoxyacetic acid (2,4,5–T) formulations and 3 pounds of 3–amino–1,2,4–triazole (amitrole) caused slight to severe injury of aerial tissues of horsenettle but did not significantly reduce the number and vigor of sprouts the following season, and that 2,4,5–T was not more effective than 2,4–D.

In July, 1955, an experiment was begun at Clemson in a pasture in which horsenettle was the principal summer weed, to determine whether the cumulative effect of annual applications of various herbicides would lead to satisfactory and economical control.

Materials and Methods

An area in an old Bermudagrass pasture was divided into plots 14 by 40 feet. Horsenettle plants were present in each plot, although infestation was not uniform over the entire area. In addition to horsenettle, certain *Rumex* and *Amaranthus* species were also present. The fully randomized herbicidal treatments were replicated four times.

The propylene glycol butyl ether ester of 2,4–D was used in 1955 and alkanolamine salts (ethanol and isopropanol series) of 2,4–D were used in 1956 and 1958. In 1955 a formulation of polychlorobenzoic acids was used and in 1956 and 1958 a formulation in which 2,3,6–trichlorobenzoic acid predominated was used. The herbicides

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[3]Bradbury, H. E. and Aldrich, R. J. A study of horsenettle (*Solanum carolinense*) and its control. Proc. NEWCC 10:232–233. 1956.

were applied in a volume of 17.4 gallons per acre on July 6, 1955 and July 23, 1956, and in 10.4 gallons per acre on August 5, 1958. Herbicides were not applied in 1957. Plant counts were made in 1957 after 2 years of treatment and in 1959, one year after the third treatment.

RESULTS AND DISCUSSION

The plant counts taken in 1957, Table 1, showed a significant reduction in horsenettle population for all treatments except those with chlorobenzoic acids. There was a further significant decrease in surviving plants in 1959 although there was an interval of 2 years between the 1956 and 1958 treatments. Although the chlorobenzoic acids were less effective than 2,4–D and amitrole, singly or in combination, the combination of 1.5 pounds of amitrole and 1 pound

Table 1. The effects of annual applications of various herbicides over a period of years on the persistence of horsenettle in a common Bermudagrass pasture. (Data recorded 2 and 4 years after treatments began.)

Herbicide	Rate lb/A	Horsenettle plants/sq yd		Control of other weeds	Bermudagrass injury
		July 1957	July 1959		
Untreated	—	6.2	10.3	none	none
Chlorobenzoic acids	2.0	7.0	7.3[a]	poor	none
Chlorobenzoic acids and amitrole	1.0 1.5	4.0	0.7[b]	poor	slight-temporary
2,4–D	4.0	3.6[a]	1.7[b]	excellent	none
2,4–D	2.0	3.0[a]	2.7[b]	excellent	none
2,4–D and amitrole	2.0 1.5	3.0[a]	0.3[b]	excellent	slight-temporary
2,4–D and amitrole	1.0 1.5	3.0[a]	0.3[b]	excellent	slight-temporary
Amitrole	3.0	3.2[a]	0.3[b]	poor	slight-temporary
LSD 5%		2.5	2.6		
LSD 1%		3.4	3.6		

[a]Indicates a reduction below untreated at 5% level of significance.
[b]Indicates a reduction below untreated at 1% level of significance.

of chlorobenzoic acids was as effective as any other treatment, indicating either that 1.5 pounds of amitrole is sufficient for effective horsenettle control or that chlorobenzoic acids increase the herbicidal activity of amitrole. Horsenettle foliage showed formative effects from treatments in previous years with chlorobenzoic acids and 2,4–D, but amitrole did not cause such effects.

From the viewpoint of practical control of horsenettle, the cumulative effect of 3 applications in 4 years of 2 pounds of 2,4–D or 3 pounds of amitrole per acre reduced the surviving plants to a small and relatively unimportant number. The use of amitrole in pastures, however, has not been cleared and even if such clearance were obtained, its higher cost along with the less effective control of other weeds would severely restrict its usefulness.

SUMMARY

1. Horsenettle infestations in a Bermudagrass pasture were greatly reduced but were not completely eliminated after 3 applications in

4 years of 3 pounds per acre of amitrole or 2 or 4 pounds per acre of 2,4–D.

2. Chlorobenzoic acids at 2 pounds per acre were less effective than amitrole or 2,4–D although some reduction in horsenettle infestation occurred.

3. Combination treatments of 1 pound of chlorobenzoic acids and 1.5 pounds of amitrole per acre or 1 or 2 pounds of 2,4–D with 1.5 pounds of amitrole per acre were highly effective in reducing horsenettle infestations.

4. Broadleaved weeds, other than horsenettle, were satisfactorily controlled only by treatments containing 2,4–D.

5. Bermudagrass was not significantly injured by any treatment used, although moderate chlorosis for 30 to 60 days followed amitrole applications.

Effect of Tansy Mustard *(Descurainia intermedia)* on Moisture Storage During Fallow[1]

A. F. Wiese[2]

Since the work of Cox and Cates (2) in 1912, it had been shown repeatedly that weeds growing in competition with crops decrease yields. These results lead to the general assumption that weeds are detrimental anytime, including a fallow period for moisture conservation. In fact many farmers in the Great Plains area still plow during the winter or when there are no weeds to promote a "dust mulch" for moisture conservation even though this practice has been shown to be of little value (6, 7). Recent research has shown that where runoff is prevented and weed control is adequate during the fallow period, type of tillage or amount of mulch does not greatly affect moisture storage in the Southern Great Plains (8). Finnell (5) stated that on the heavy soils of the Southern Great Plains 65.8 percent of the rainfall was evaporated, 13.5 percent was runoff, 2.7 percent was lost in tillage operations and 18.0 percent was stored in the soil.

Considering the large proportion of rainfall that evaporates, it is possible that some transpiration from small plants may not effect the soil moisture storage during fallow. In order to test this contention, a preliminary study was conducted to compare the moisture losses from a heavy infestation of winter annual tansy mustard and stubble mulch fallowed ground.

Methods

The soil type on the experimental area was Pullman silty clay loam which has been previously described (3). It is a calcareous reddish chestnut soil with a very slow intake rate. There are about 9 and 17 inches of water in the top 4 feet of soil at wilting point and field capacity.

The experiment was conducted on two plots; one was weed-free, stubble-mulched soil and the other was growing tansy mustard. (*Descurainia intermedia*). The weed-free plot was maintained with a 30-inch sweep plow. Moisture losses were determined gravimetrically on the two plots from January 16, 1958, when the weeds were in the rosette stage, until June 2, 1958, when the weeds were mature. The weeds had emerged in late October. Three soil samples were taken on each plot to a depth of four feet, eight times during the experimental period. The soil moisture data were subjected to an analysis of variance for a single variable of classification as suggested

[1]Work was conducted cooperatively between Texas Agricultural Experiment Station and Western Soil and Water Management Research Branch, SWCRD, ARS, USDA. Approved as TAES T.A. 3421.

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by Dixon and Massey (4). The variance within samples was used to test the significance of treatments.

RESULTS

The soil moisture and rainfall data obtained at various times during the study were used to calculate moisture losses from the weedy and weed-free plots, Figure 1. Both plots had about four inches

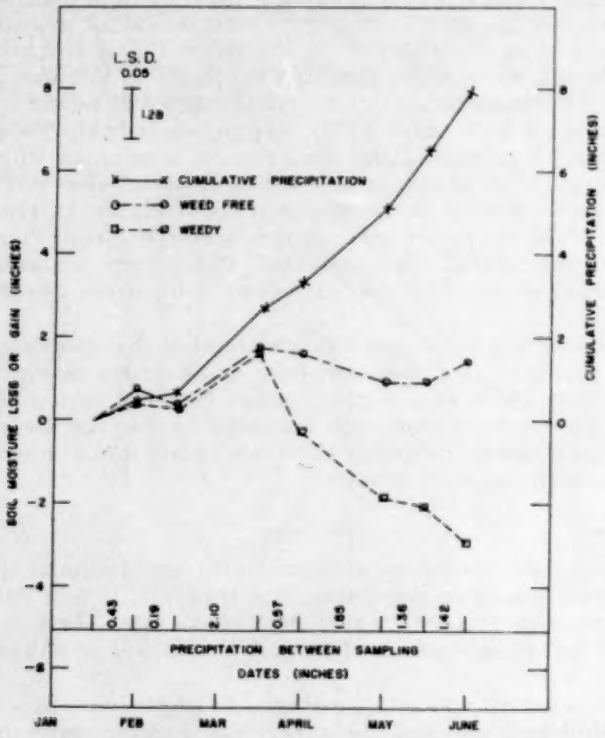

Figure 1. Cumulative precipitation and soil moisture losses during the fallow period from weed-free and weedy plots. (Evaporation is the difference between cumulative precipitation and moisture gain on the weed-free plot, and water use by weeds is the difference between moisture gain on weed-free plot and moisture loss on weedy plot.)

of available soil moisture at the start of the study. The total evapotranspiration from January 16 to June 2 on the weedy plot was 10.86 inches. Evaporation from the weed-free plot was 6.46 inches. From the standpoint of soil moisture storage, transpiration can be considered as the difference in moisture loss between the weedy and the weed-free plots or 4.40 inches. During the entire study period, 1.46 inches or 18 percent of the rainfall was stored on the weed-free plot.

Moisture loss on the weedy plot was similar to the weed-free plot until March 15, when the weeds were 3 to 4 inches tall. The weeds were extracting moisture from a depth of 2 feet April 1 and 4 feet by May 1. At the end of the study, the weeds had reduced the soil moisture 2.94 inches.

At maturity the weeds produced 2,190 pounds of dry top growth per acre. The water requirement (pounds of water to produce a pound of dry matter) was 1,121 when total evapotranspiration, 10.86 inches, was used in the calculation. The water requirement was only 454 when transpiration only was considered. Briggs and Shantz (1) working at Akron, Colorado, under an environment similar to Bushland, Texas, determined the water requirement for many weed species. They grew plants in pots with the soil surface sealed to prevent evaporation. The water requirements varied from 277 for *Amaranthus graecizans* to 948 for *Ambrosia artemisifolia*.

SUMMARY

This study indicates that small weeds are not always detrimental to soil moisture storage during a fallow period. Winter annual tansy mustard that emerged in October did not utilize soil moisture in excess of the amount of evaporation from bare soil until after March 15. This study suggests that considerable research should be conducted to determine the interrelationships among weed species, stage of weed growth, season of weed growth, soil characteristics, and various climatic factors on the efficiency of moisture storage during fallow periods.

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News and Notes

The officers of the Weed Society of America for 1960–61 are: President, K. P. Buchholtz, University of Wisconsin, Madison; Vice-President, Warren C. Shaw, U.S.D.A., Beltsville, Maryland; Secretary, F. W. Slife, University of Illinois, Urbana. The next meeting will be held at St. Louis, Missouri, Dec. 11 to 14, 1961, as guests of the North Central Weed Control Conference.

The next meeting of the North Central Weed Control Conference will be held at the Schroeder Hotel in Milwaukee, Wisconsin, December 12 to 15, 1960. The 1960 officers are: President, L. G. Holm, Department of Horticulture, University of Wisconsin, Madison 6; Vice-President, E. K. Alban, The Ohio State University, 1827 Neil Ave., Columbus 10, Ohio; Secretary-Treasurer, J. D. Furrer, Department of Agronomy, University of Nebraska, Lincoln, Nebraska. The 1959 Proceedings, which includes the printed Research Reports, can be obtained from the Secretary-Treasurer for $4.00.

The next meeting of the Northeastern Weed Control Conference will be held at the Hotel New Yorker, January 4, 5, and 6, 1961. The officers are: President, E. M. Rahn, Department of Horticulture, University of Delaware, Newark; Vice-President, Lawrence Southwick, Dow Chemical Co., Midland, Michigan; Secretary-Treasurer, D. A. Schallock, Department of Farm Crops, Rutgers University, New Brunswick, New Jersey. The Proceedings for 1960 can be obtained from the Secretary for $4.00, and the Supplement to the Proceedings for $2.00.

The next meeting of the Southern Weed Conference will be at Hotel Soreno, St. Petersburg, Florida, January 18 to 20, 1961. The officers are: President, R. A. Darrow, Texas A. & M. College, College Station; Vice-President, Walter K. Porter, Louisiana State University, Baton Rouge; and Secretary-Treasurer, R. E. Frans, University of Arkansas, Fayetteville. The 1960 Proceedings of the Southern Weed Conference can be obtained from Dr. Frans for $3.50.

The officers of the Western Weed Control Conference are: President, W. R. Furtick, Oregon State College, Corvallis; Vice-President, Eugene Heikes, Montana State College, Bozeman; Secretary-Treasurer, E. J. Bowles, 3239 Mayfair Boulevard, Fresno, California. The next meeting of the Research Section of the WWCC will be held in Salt Lake City, March 21 and 22, 1961. The Research Progress Report for 1960 can be obtained from the Secretary for $2.00.

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for
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This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Crops Research Division, Agricultural Research Service, U.S.D.A. does not assume responsibility for the subject matter cited.

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